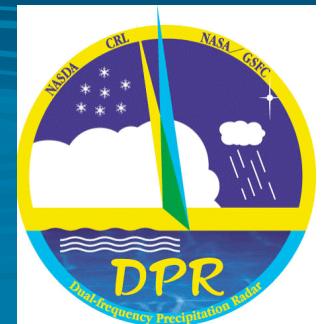




DPR hardware calibration

Katsuhiro Nakagawa (NiCT, GEST/UMBC)
Hirosi Hanado (NiCT)
Toshio Iguchi (NiCT)



Outline

📁 What is Calibration/Validation ?

📄 NICT activities on GPM/DPR

📋 Summary



DPR/GPM Calibration/Validation

Engineering values

Transmit power,
Received power,
Antenna beam direction

Sensor hardware calibration
(Level1 data validation)

Algorithm

DSD (drop size distribution),
Classification (Convective/Stratiform),
Particle type,
temperature & humidity profile,
Melting layer model,
Gaseous attenuation, ...

Algorithm validation

Physical values

Rainfall rate, Rain accumulation
Liquid/Ice water content,
Precipitation type classification,
Latent heat release,

Products validation
(Level 2 and 3 data validation)

GV Super Site @ NICT Okinawa
For algorithm validation
products validation



NICT activities on GPM/DPR

- Development of KaPR RF engineering model
 - Developed in 2006
 - Antenna pattern measurement in Spring 2007
- Calibration strategy of GPM/DPR with RC
- Development of GPM/DPR dual frequency algorithm
 - presentation from Dr. Shimizu (JAXA)
- Validation and verification strategy of GPM/DPR
 - presentation from Dr. Shimizu (JAXA)
- Ground validation super site at NICT Okinawa



Schedule for development

2007/04

2008/04

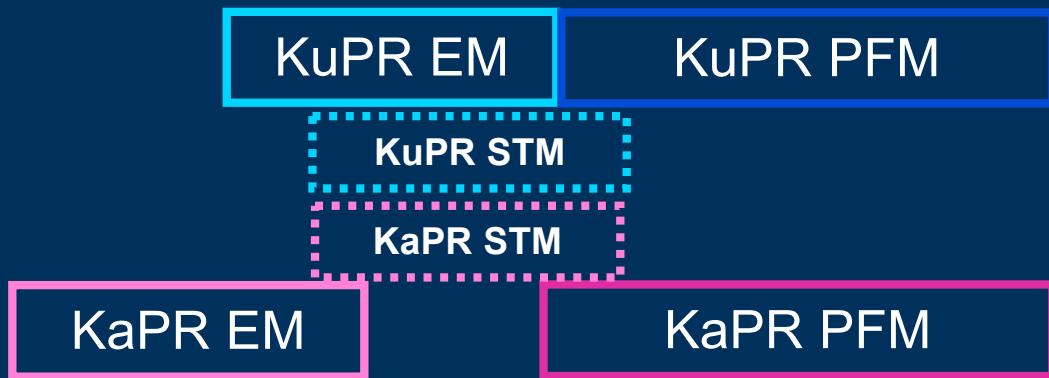
2010/12

2011/06

2013/07

completed
⇒ NASA

launch



Hardware

Software

DPR algorithm ver.1

DPR algorithm ver.2

DPR algorithm ver.3

prototype algorithm

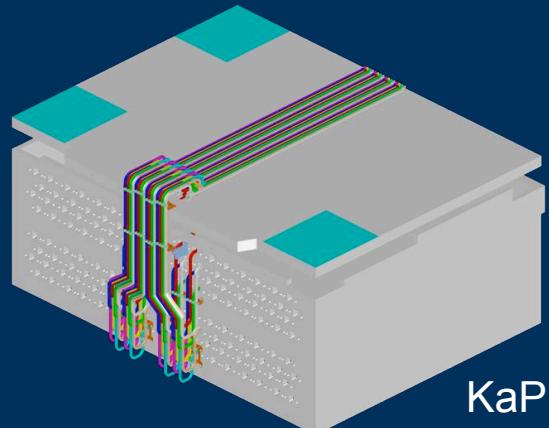


STM: Structure Thermal Model
PFM: Proto Flight Model

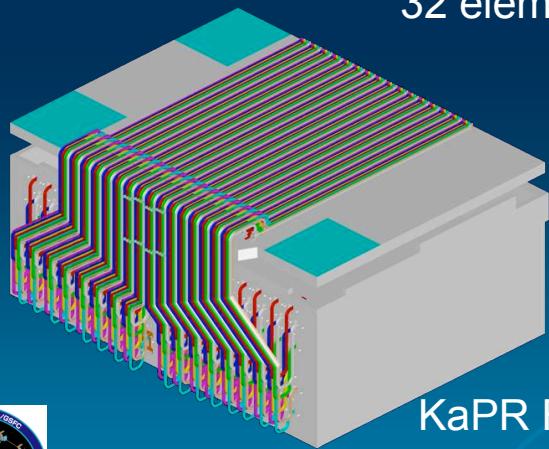


KaPR RF engineering model

KaPR EM consists of 32 elements of waveguide slot array antenna.



KaPR EM
32 elements



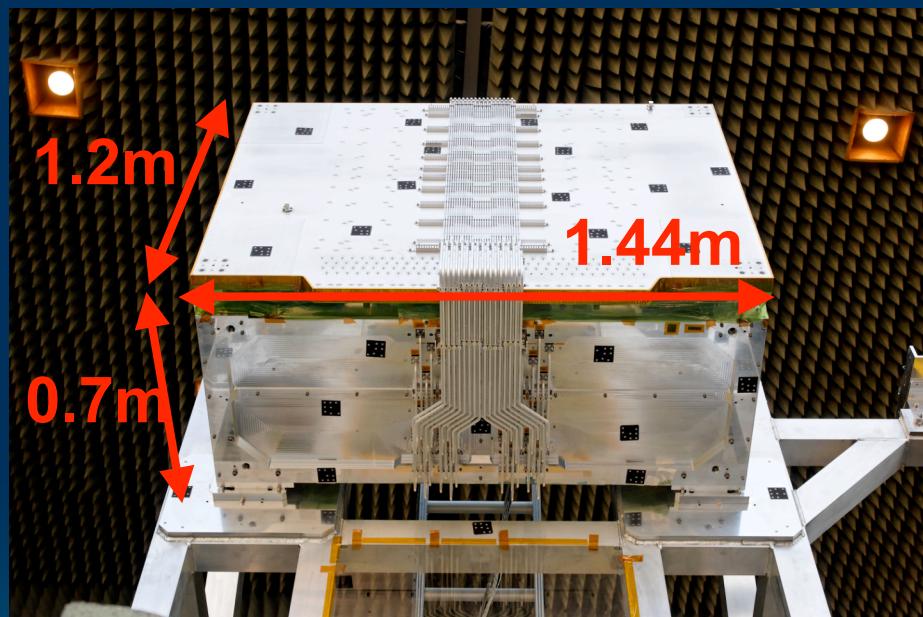
KaPR Flight model
128 elements



KaPR EM and Supporting structure



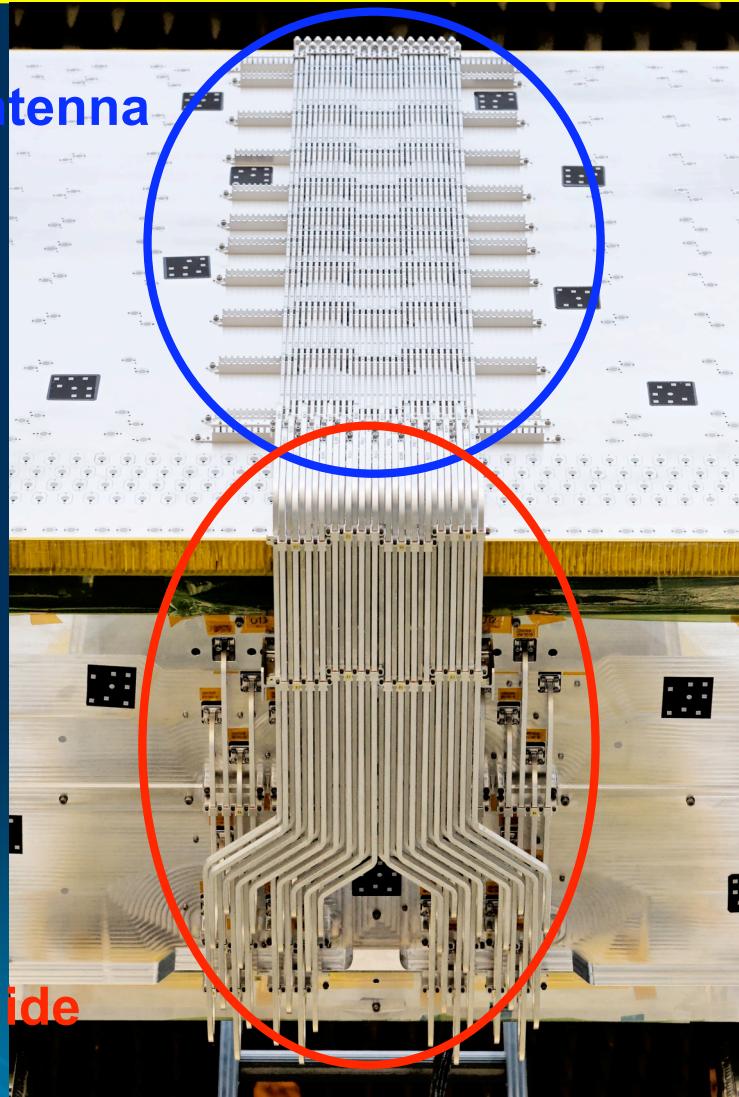
KaPR RF engineering model (cont.)



waveguide slot array antenna

The radioelectric size between the transmitter unit and the antenna is consistent in length for phase consideration.

waveguide

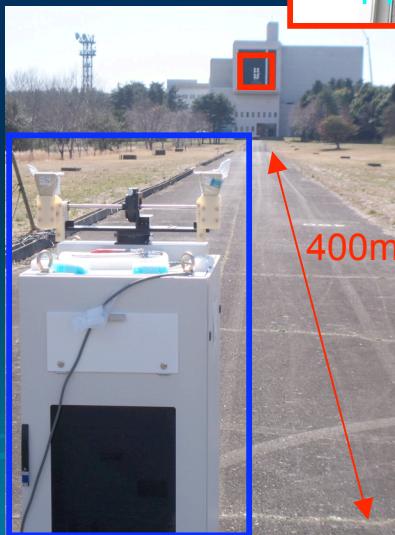


KaPR RF link system test



Active Radar Calibrator (ARC)

- (A). Transmit beacon (CW) \Rightarrow Receiver Receiving antenna pattern measurement
- (B). Receiver \leq Transmitter Transmit antenna pattern measurement
- (C). Transponder \Leftrightarrow radar function test



NICT activities on GPM/DPR

- Development of KaPR RF engineering model
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- Development of GPM/DPR dual frequency algorithm
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DPR calibration

- DPR external calibration using radar calibrator (RC)
 - Absolute calibration of Z measurement (same idea as TRMM/PR)
 - Antenna pattern measurement (same idea as TRMM/PR)
 - Confirmation of beam matching between two radars (new task for GPM/DPR)
- lessons from external calibration of TRMM/PR
 - On DPR antenna scanning at external calibration mode, better resolution in cross-track direction would be helpful. But it is trade off with that in along-track direction.
 - Multiple RCs (receivers) are beneficial to determine the antenna beam center position.
 - Transponder function of ARC is not effective to improve power measurement accuracy.



Two methods for confirmation of DPR beam matching

	method	merit	demerit
1	external calibration with RCs (Radar Calibrators)	accuracy	<ul style="list-style-type: none">1. only one angle bin at one experiment2. experiment site is limited (around Tsukuba, Japan)3. exclusive to observation mode4. expensive
2	pattern matching with specific echoes	<ul style="list-style-type: none">1. no limitation of location2. compatible with observation mode	<ul style="list-style-type: none">1. need large data for statistical analysis2. must develop algorithm and confirm its accuracy



NICT activities on GPM/DPR

- Development of KaPR RF engineering model
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DPR GV Super Site at NICT Okinawa



NICT Okinawa



NICT Ogimi
(400MHz WPR Radar Site)



NICT Nago
(COBRA Radar Site)

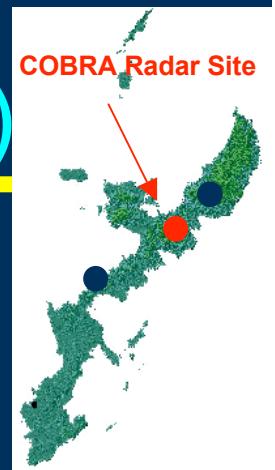


COBRA (C-band polarimetric radar)

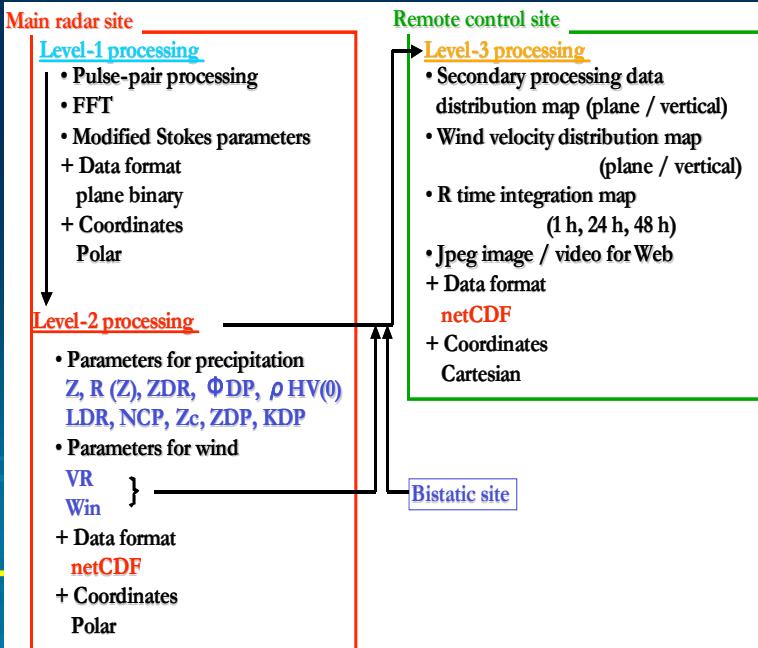


Specifications

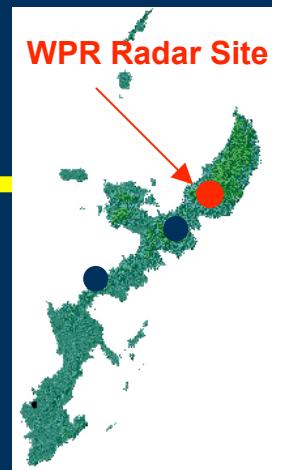
Peak power	> 250 kW (Dual Klystron)
Pulse width	0.5 μ s, 1.0 μ s, 2.0 μ s (Klystron) 0.5 – 100 μ s (TWTA)
PRF (staggered PRF)	250 Hz - 3000 Hz, PRT 1 μ s step
Antenna size	4.5m φ parabolic
Beam width	0.91deg
Radome size	8m φ
Cross pol. ratio	> 36 dB (Integrated value in a beam)
Antenna gain	45 dBi (including radome)
Sidelobe	< -27 dB (one way)
Ant. scan speed	0.5-10 rpm(PPI), 0.1-3.6 rpm(RHI), 0.1 rpm step
Polarization	H, V, +45, -45, LC, RC (pulse by pulse)



Data Processing



400MHz- Wind Profiler



- Joss-type disdrometer
- Optical rain gage
- Meteorological obs.
- Micro Rain Radar
- 2D-Video Disdrometer

Specifications

Radar Type	Pulsed Doppler Radar
Frequency	443.0 MHz
Peak Power	20 kW
Average Power	2 kW
Pulse Length	1.33, 2.0, 4.0 μ s
Pulse Repetition Frequency	6.25, 20 kHz
Antenna Type	24 × 24 element crossed array
Antenna Size	10.4 m × 10.4 m
Beam Width	3.3°
Beam Steerability	
Azimuth	0 - 360°
Zenith	0 - 15°
Observation Items	Vertical profiles of wind velocity, rainfall intensity, and virtual temperature

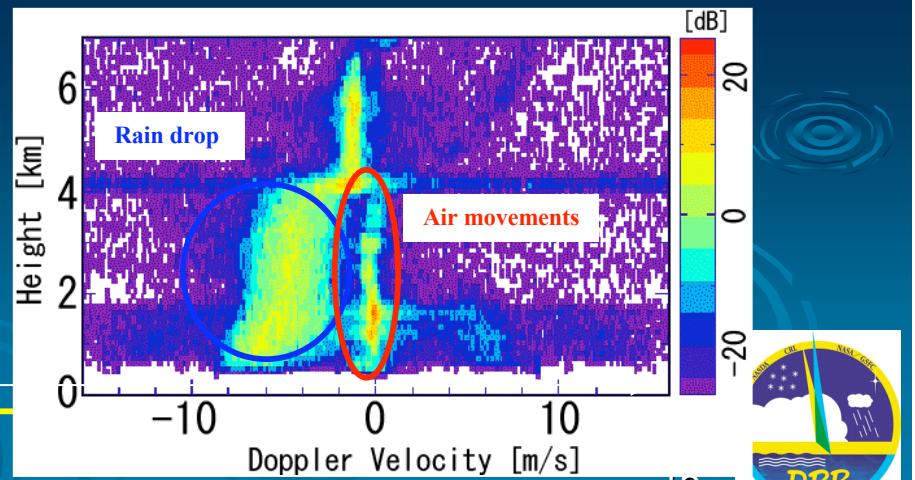
Data Processing

Process level	Data format	Parameters
Level-1	netcdf	Doppler spectral
Level-2	netcdf	Echo Power, Doppler Velocity, and Noise (along radial direction)
Level-3	csv	Wind velocity of the E-W direction, N-S direction, and vertical direction

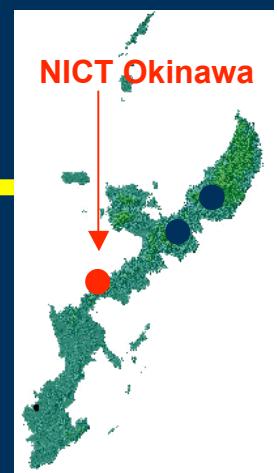
$$S_{obs}(v) = P_t S_t(v) + S_D(v) * S_t(v) + P_n$$

$$S_D(v) \propto C \cdot N(D) \cdot D^6 \cdot dD/dv$$

$$S_t(v) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(v - v_0)^2}{2\sigma^2}\right]$$



NICT Okinawa (Onna)



- Joss-type disdrometer
- Optical rain gage
- Micro Rain Radar
- Meteorological obs.

Joss-type disdrometer



Optical rain gage



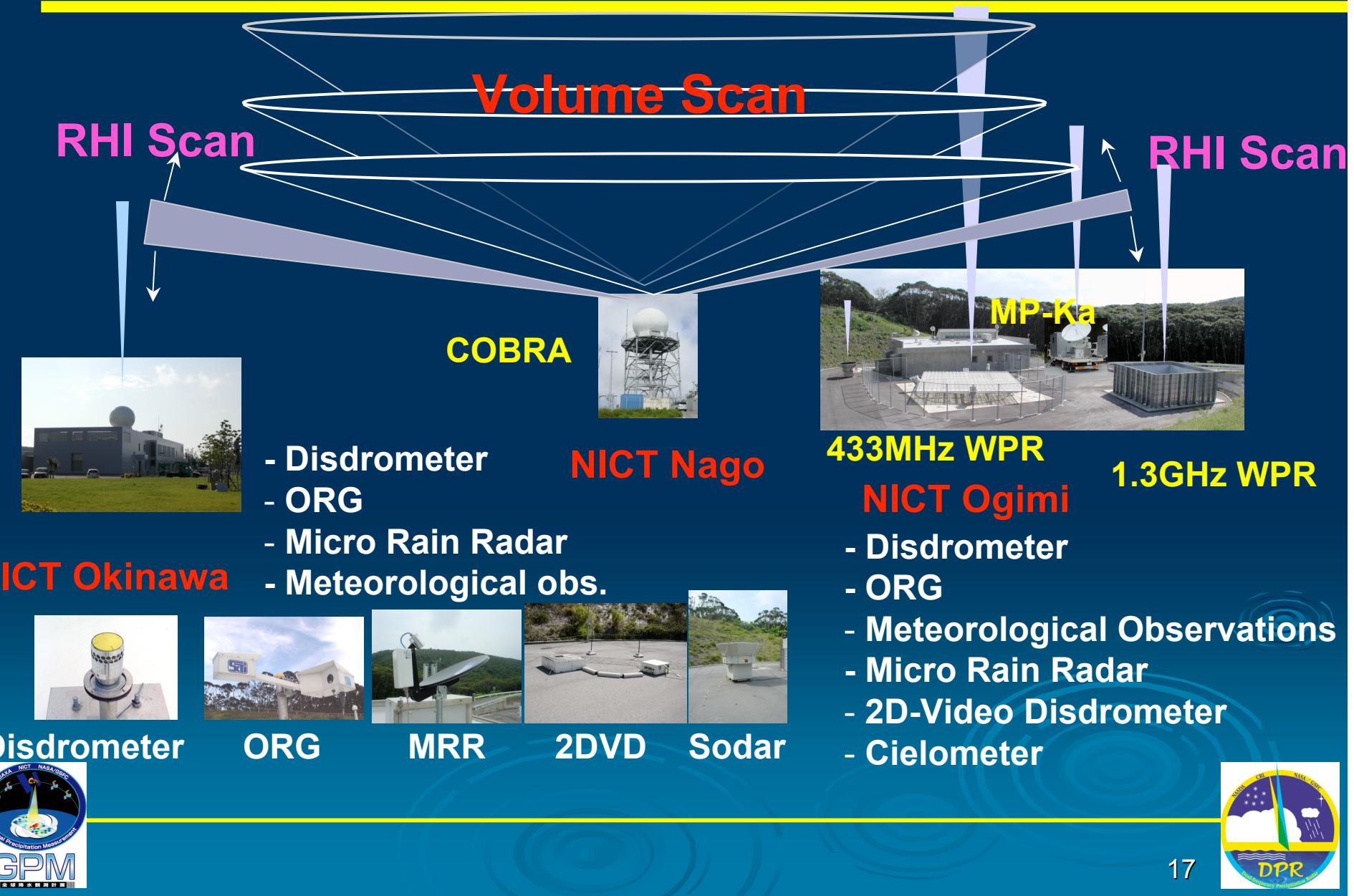
2D-Video Distrometer
(Kyoto Univ.)



Micro rain radar
(Nagoya Univ.)



Field Campaign (okn-baiu04:May 22- June 9, 2004)



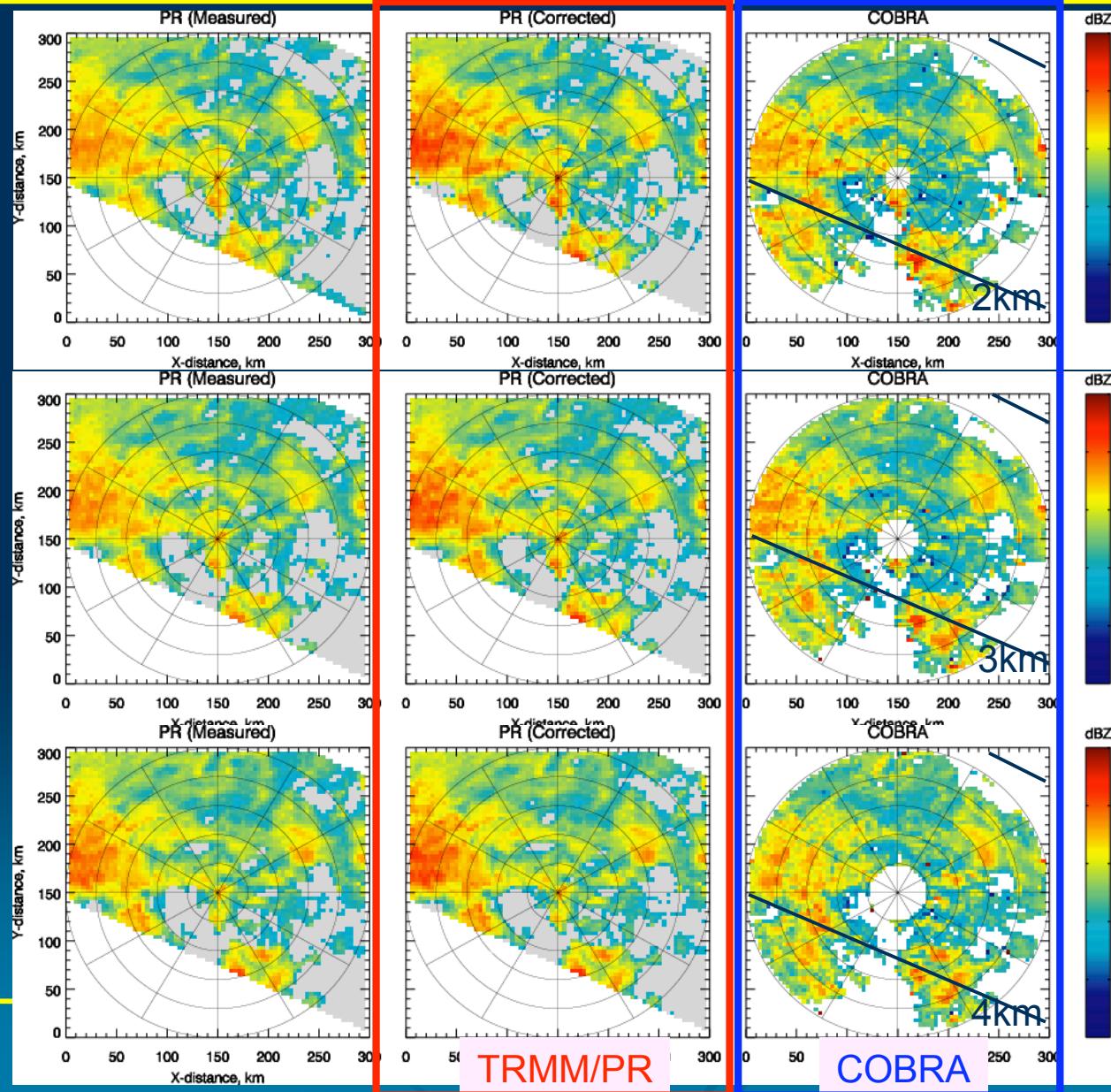
Products validation

TRMM over-passed cases during the campaign observation (okn-baiu04)

	CASE 1	CASE 2
TRMM/PR Orbit #	37135 2004/06/02	37437 2004/06/09
COBRA	2004/06/02 02:10-02:20	2004/06/09 22:00-22:10
2DVD	2004/06/02 00:30-6:00	2004/06/09 16:00-22:00



Comparison of horizontal radar reflectivities for the TRMM/PR(2A25) and COBRA

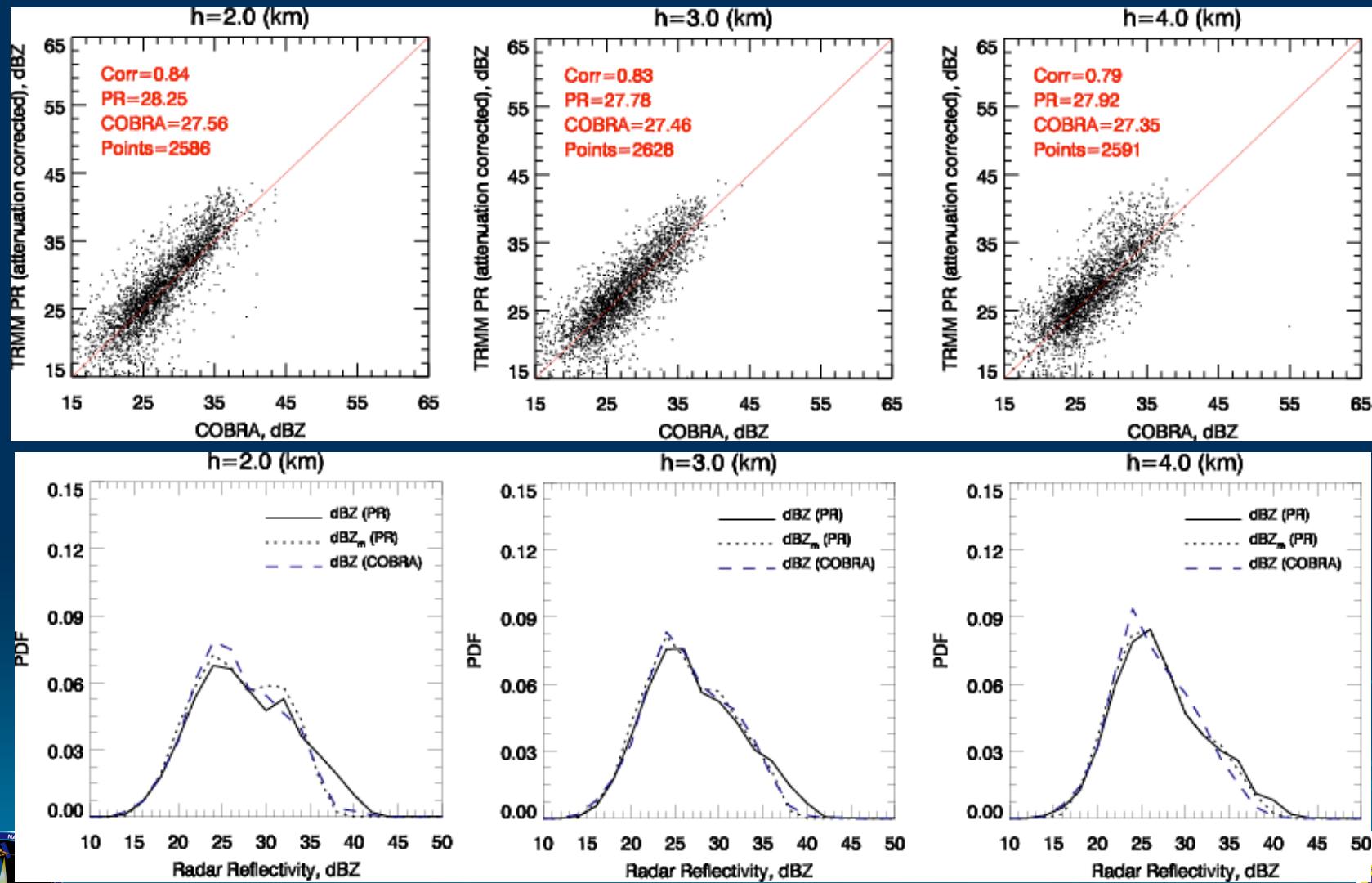


CASE1



Scatter plots and the probability density function (pdf)

CASE1



Algorithm validation (k - Z relationship)

The k - Z relationship for the Ku-band(13.8GHz),

$$k_{rain} = \alpha Z^{\beta}$$

is estimated by use of 2D-Video Distrometer.

The specific attenuation k [dB/km] is expressed as;

$$k_{rain} = 4.343 \times 10^{-3} \int_{D_{min}}^{D_{max}} N_{rain}(D) \cdot \sigma_{ext}(D) dD$$

The radar reflectivity Z [$\text{mm}^6 \text{ m}^{-3}$] is expressed as;

$$Z = \frac{\lambda^4}{\pi^5 |K|^2} \int_{D_{min}}^{D_{max}} \sigma_{bks} N_{rain}(D) dD$$

A unit of $N(D)dD$ is [m^{-3}].

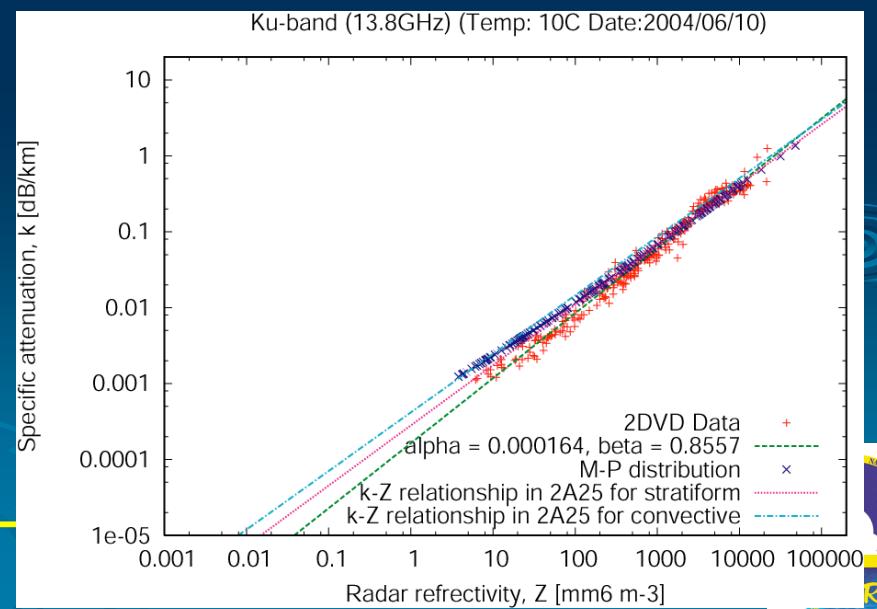
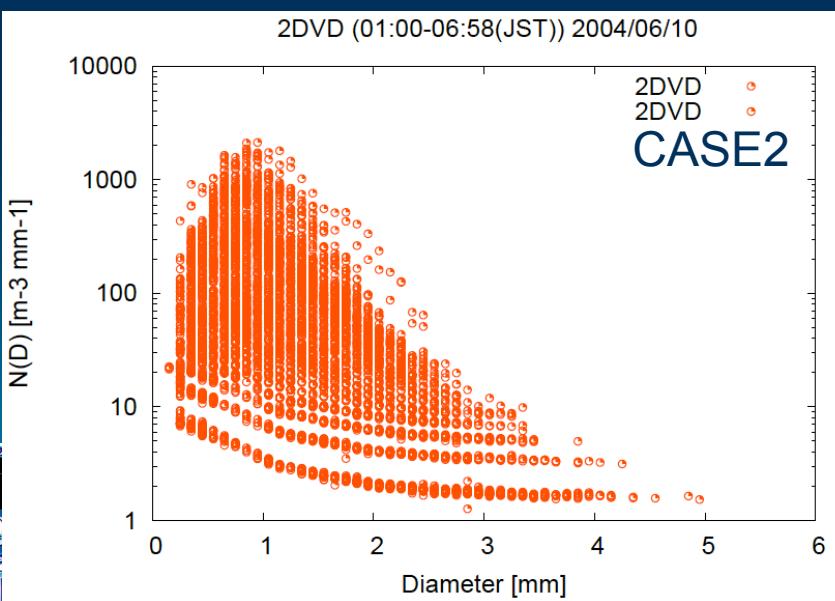
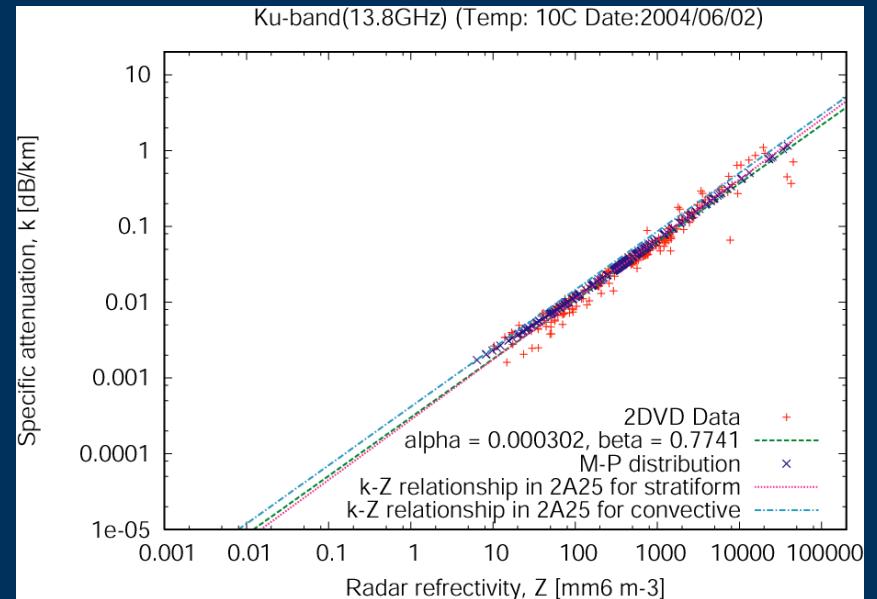
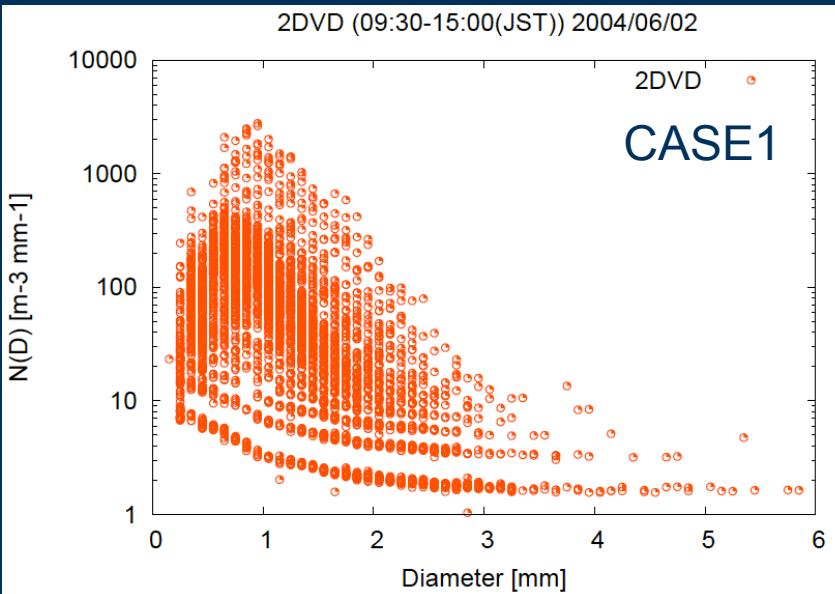
σ_{ext} and σ_{bks} can be processed by the Mie scattering theory.

σ_{ext} [mm^2] is the extinction cross section.

σ_{bks} [mm^2] is the back scattering cross section.



k -Z relationship (cont.)



Summary

- Calibration/Validation
 - Sensor hardware calibration, Algorithm validation, Products validation
- KaPR RF Engineering Model (EM)
 - Development, Antenna pattern measurement
- Radar Calibrator (RC)
 - Development, calibration experiment
- GV super site at NICT Okinawa
 - Three facilities in NICT Okinawa
- Algorithm validation / Products validation
 - Some results of the field campaign (okn-baiu04)

- 👉 The radar reflectivities from the TRMM/PR (2A25) correspond with the reflectivities from the COBRA.
 $-1.5 \text{ dBZ} < Z_{\text{TRMM}} - Z^{\text{COBRA}} < 1.0 \text{ dBZ}$
- 👉 The k-Z relationship is conducted by use of the 2DVD data.



Back up



Evaluation for k - Z relationship using COBRA

Procedure

The k - Z relationship will be conducted by use of COBRA data.

$$N(D) = N_0 \exp(-\Lambda D)$$



$$\Lambda = 2.603 \cdot Z_{DR}^{-0.63} \quad : \text{Seliga and Bringi (1976)}$$
$$Z = \frac{N_0 \cdot 6!}{\Lambda}$$

$$k_{cobra@13.8GHz} = 4.343 \times 10^{-3} \int_{D_{min}}^{D_{max}} N(D)_{COBRA} \cdot \sigma_{ext}(D) dD$$

$$Z_{cobra@13.8GHz} = \frac{\lambda^4}{\pi^5 |K|^2} \int_{D_{min}}^{D_{max}} \sigma_{bks} N_{COBRA}(D) dD$$



Evaluation for k -Z relationship (cont.)

$$k = \alpha Z^{\beta}$$

Z [mm⁶ m⁻³]

k_{rain} [dB/km]

TRMM/PR 2A25
convective: 0.7713
stratiform : 0.7923

For each points

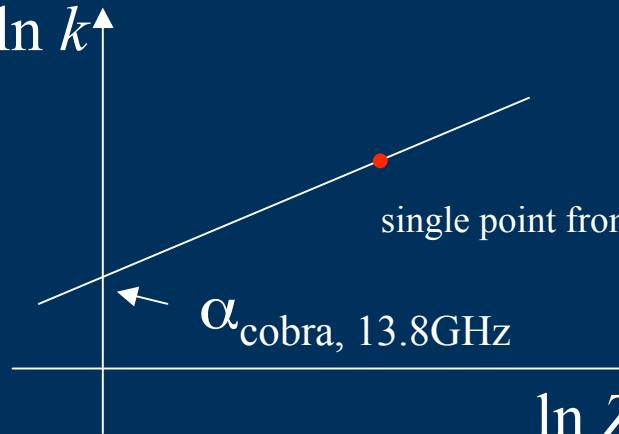
$$k_{cobra, 13.8GHz} = \alpha Z^{\beta_{2A25}}$$

$$\ln k_{cobra, 13.8GHz} = \ln \alpha + \beta_{2A25} \cdot \ln Z$$

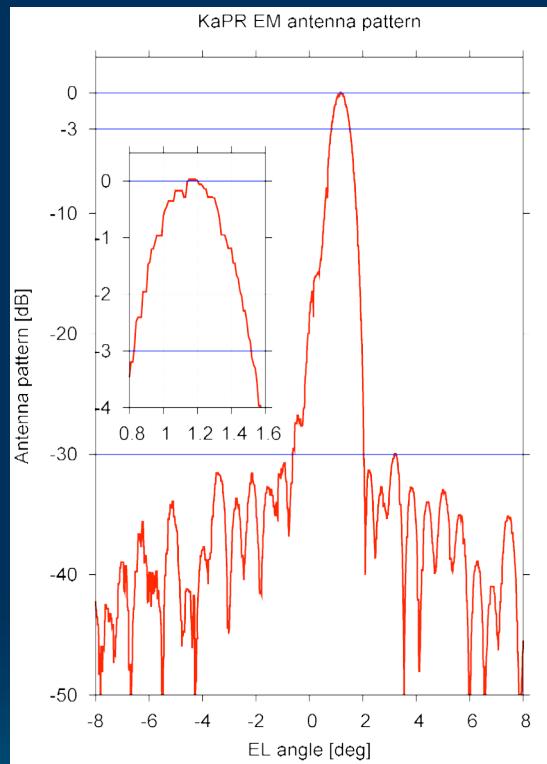
$$\Rightarrow \alpha_{cobra, 13.8GHz} = \exp(\ln k_{cobra, 13.8GHz} - \beta_{2A25} \cdot \ln Z)$$

$$\varepsilon_{cobra} = \frac{\alpha_{cobra, 13.8GHz}}{\alpha_{2A25 init}} \Leftrightarrow \varepsilon_{2A25}$$

compare

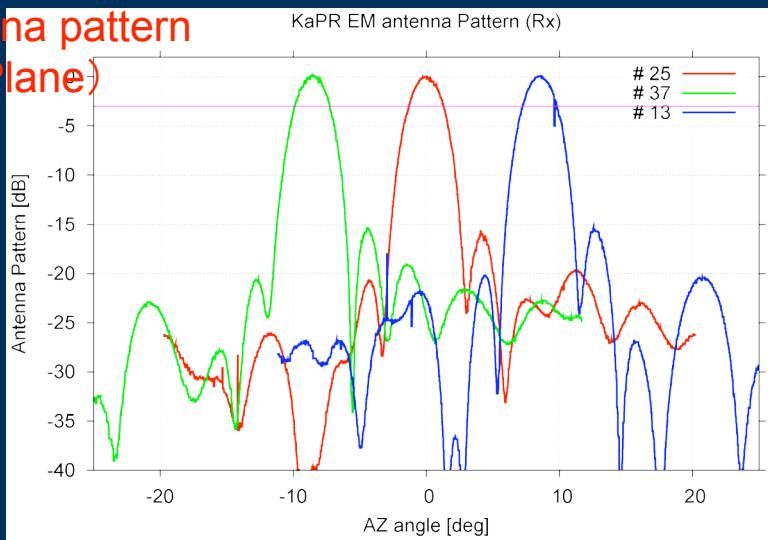


Antenna pattern

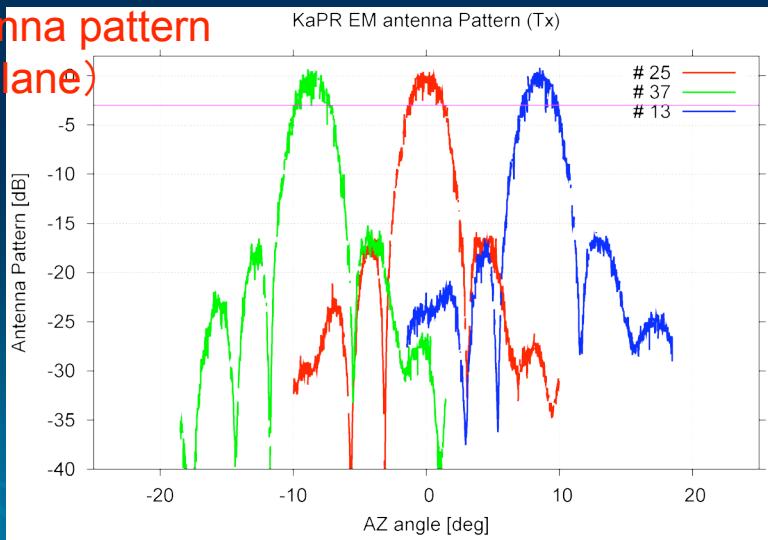


Received antenna pattern
(Elevation Plane)

Received antenna pattern
(Azimuth Plane)



Transmitted antenna pattern
(Azimuth Plane)



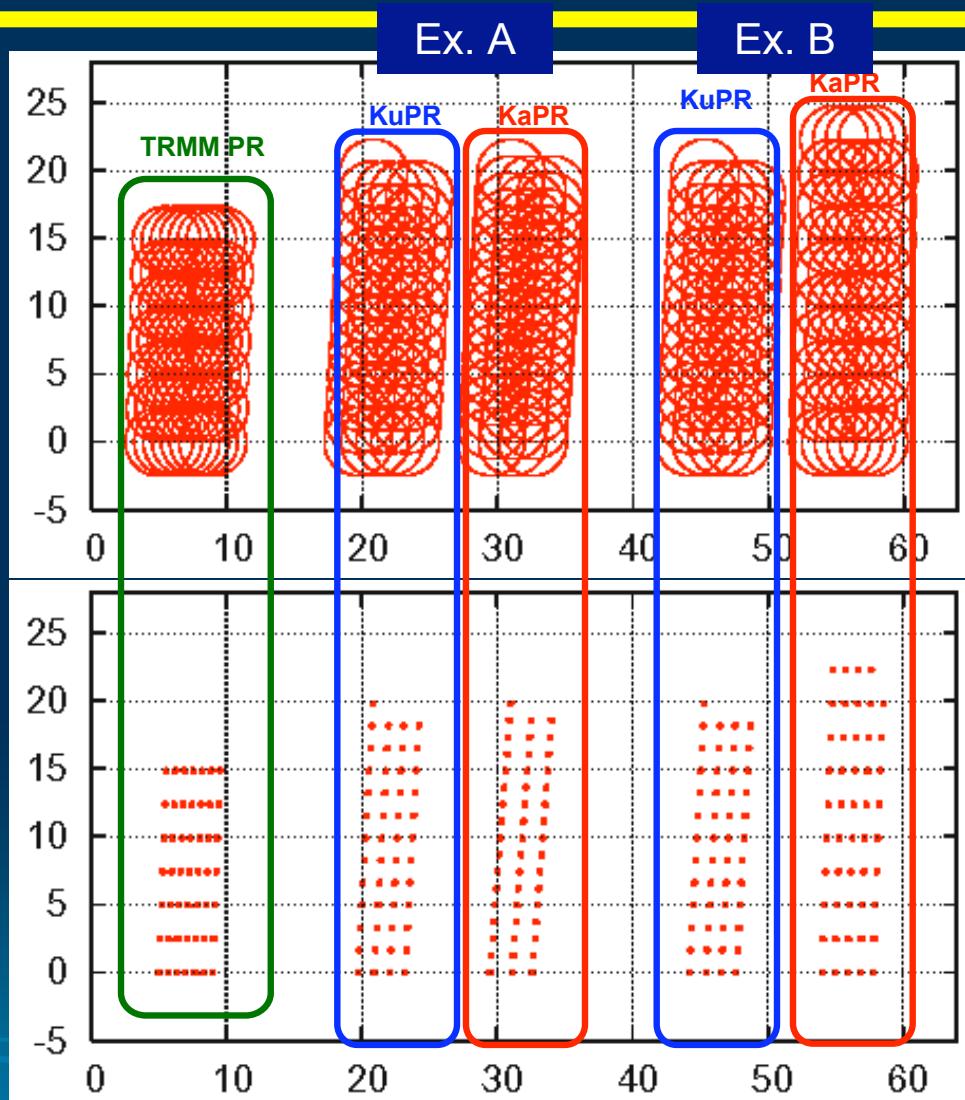
DPR external calibration mode

Beam scanning at DPR external calibration mode is so flexible that 49 beam directions in one scan (0.7 sec) are set up by commands from ground.

Both resolution in **cross-track direction** and that in **along-track direction** is adjustable.

Two examples of beam scanning for external calibration mode is the following:

	cross-track resolution (footprint)		along-track resolution (footprint)		subscan	
PR	Ku	Ka	Ku	Ka	Ku	Ka
A	1/3	1/4	1/4	1/3	13 +12 +12 +12	17+16+16
B	1/3	1/2	1/4	1/5	+12 +12 +12	10+10+10+10+9
PR	1/2		1/7		7+7+7+7+7+7+7	



along-track direction



28



cross-track direction

DPR calibration

KuPR/KaPR parameters and functions to be measured or confirmed in orbit

Initial Checkout Phase (two months after launch)

measurement item		DPR Operational mode	Satellite Attitude (yaw angle)	number of times during initial checkout phase	point		
Transmit Power		External Calibration	0 or 180 deg	8	Tsukuba (JAXA) or Koganei (NICT) in Japan		
Pulse Width							
Received Power			90 or 270 deg	2			
VPRF function							
Antenna Pattern	along-track		0 or 180 deg	8			
Antenna Beam Width	cross-track						
Input-output characteristics of both FCIF and SCDP		Internal Calibration	once a day				
TR module check	LNA	LNA analysis	0 or 180 deg	once a week	ocean		
	SSPA	SSPA analysis					



DPR calibration

KuPR/KaPR parameters and functions to be measured or confirmed in orbit

Operational Phase

measurement item	DPR Operational mode	Satellite Attitude (yaw angle)	frequency	point	
Transmit Power	External Calibration	0 or 180 deg	twice a year	Tsukuba (JAXA) or Koganei (NICT) in Japan	
Pulse Width					
Received Power					
VPRF function		90 or 270 deg	twice a year		
Antenna Pattern	along-track				
Antenna Beam Width	cross-track				
Antenna	along-track	0 or 180 deg	once a month		
Beam Width	cross-track				
Input-output characteristics of both FCIF and SCDP	Internal Calibration				
TR module check	LNA	LNA analysis	0 or 180 deg	when TR module failure is detected by HK telemetry	
	SSPA	SSPA analysis			



Beam matching between KuPR and KaPR

Matching of observation volumes between both two radars, KuPR and KaPR, is essential for DPR two-frequency algorithm.

Hardware design points for similar shape in DPR observation volume

antenna pattern	Antenna type (slotted wave guide array) and excitation current (Taylor weighting, sidelobe level -35 dB) is same.
transmit pulse waveform	RF pulse signal is amplified with broadband SSPA.
receiving filter	IF frequencies (60 MHz, 66 MHz) are same, and band pass filter is the same design.

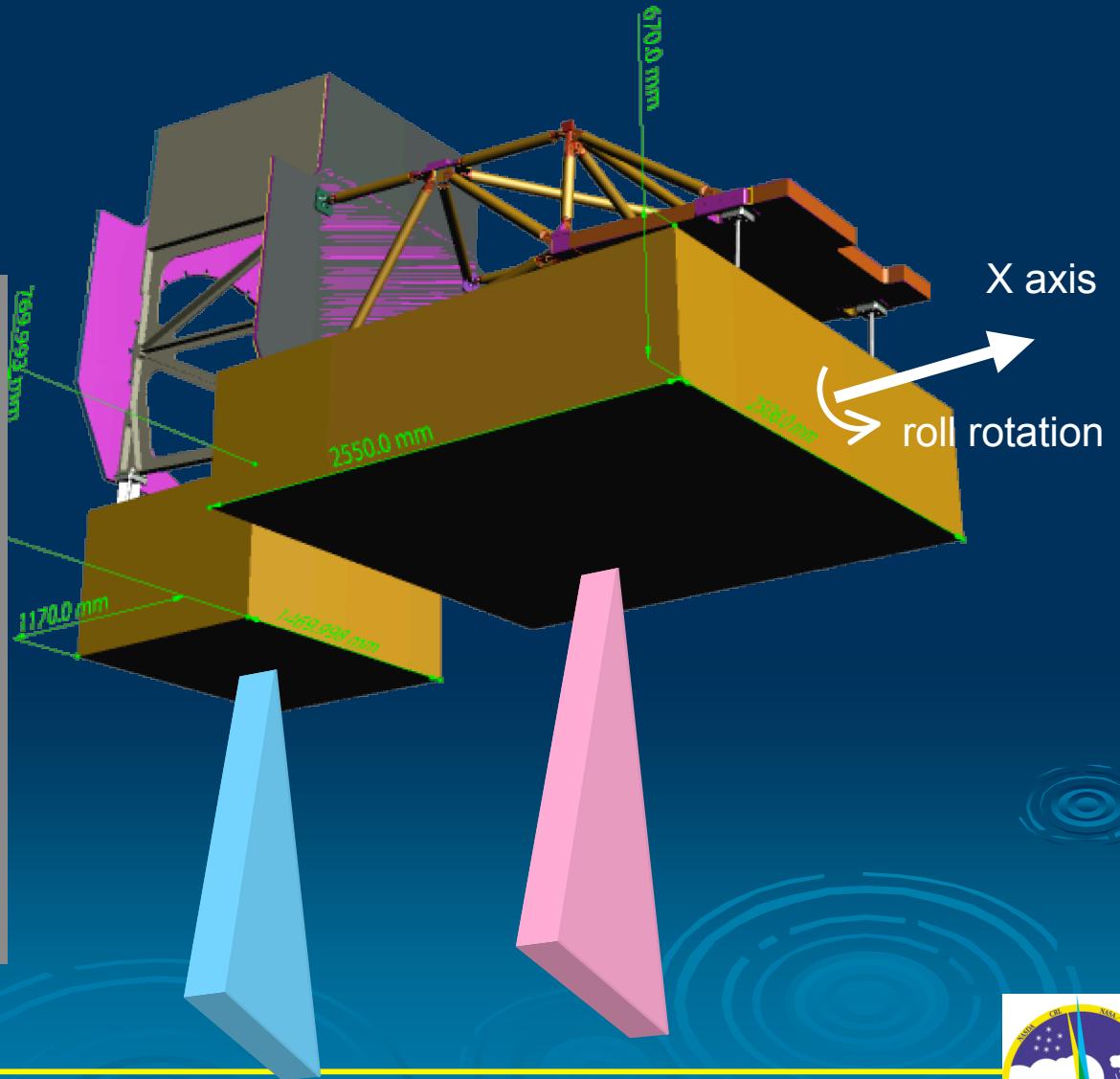
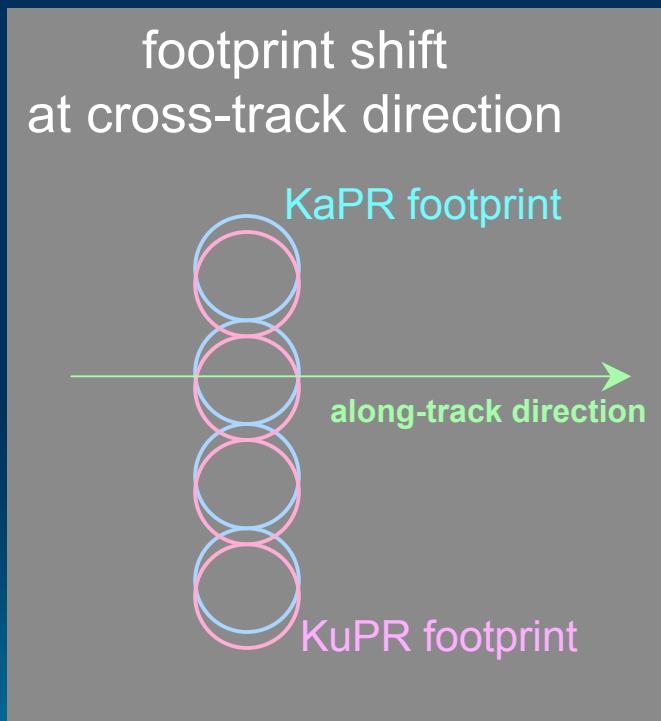
Beam matching is a key function of DPR (= KuPR + KaPR).

DPR beam adjustment method

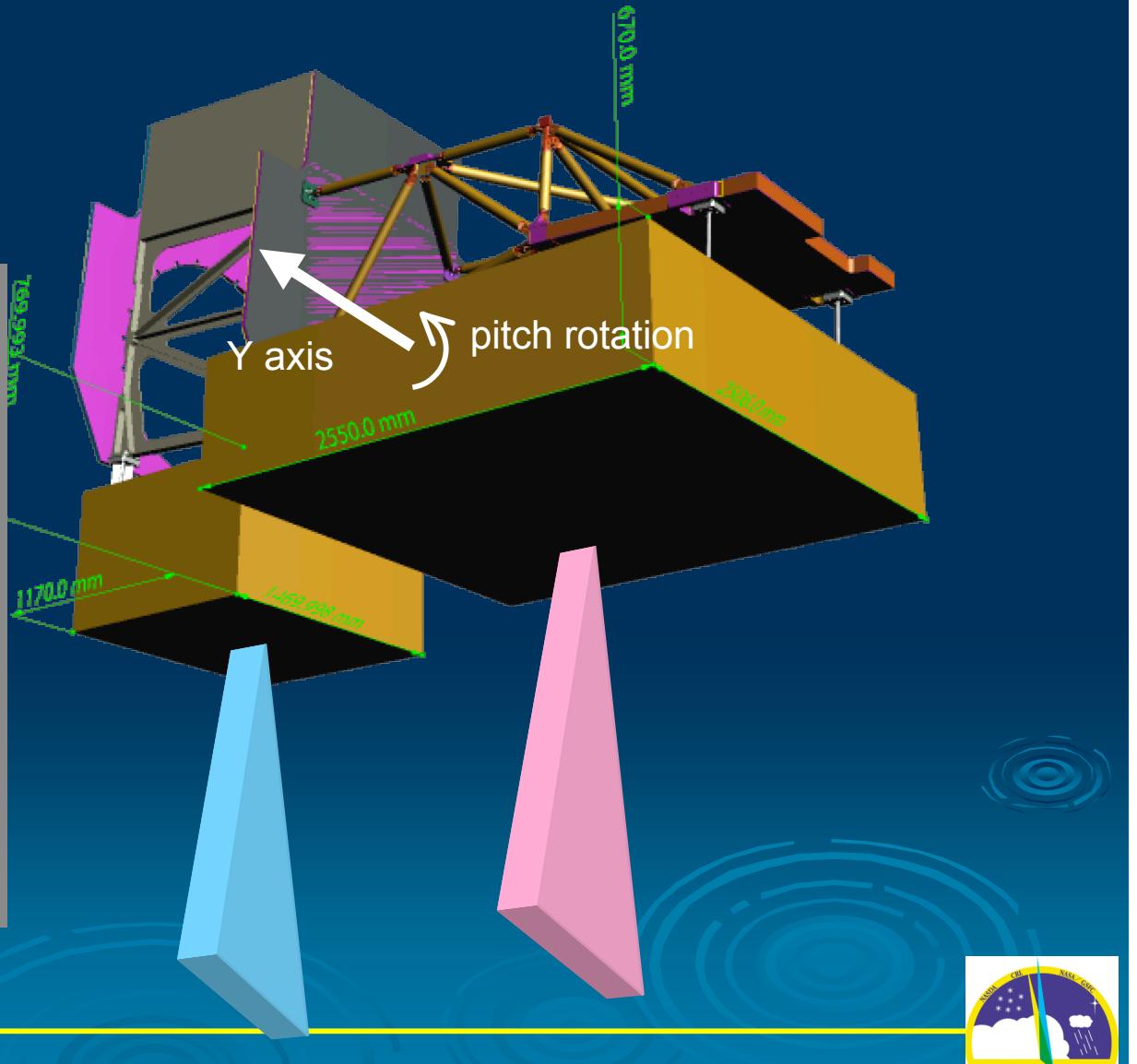
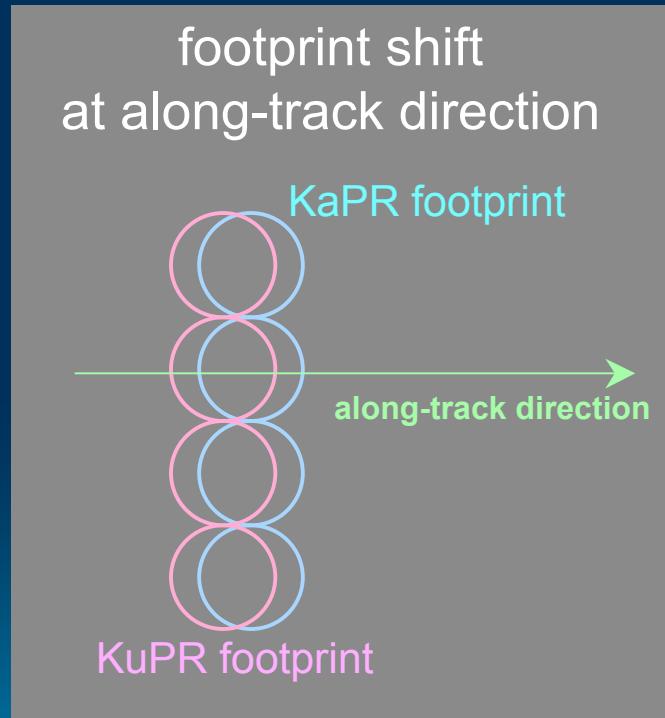
rotation axis	footprint shift direction	adjustment method
roll (x axis)	cross-track direction	phase information at phase shifters
pitch (y axis)	along-track direction	scan start time difference between KuPR and KaPR
yaw (z axis)	rotation of scan plane	



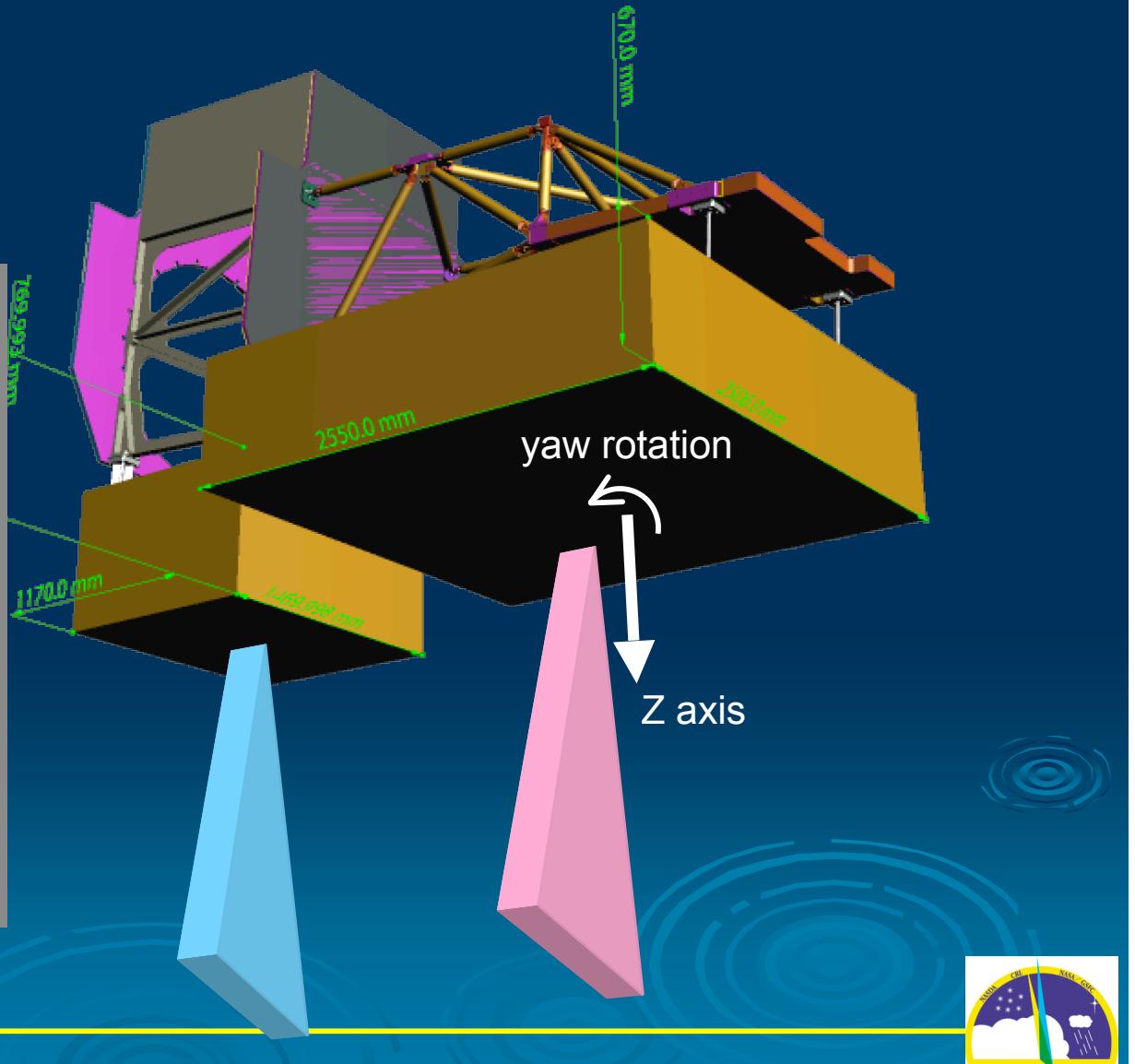
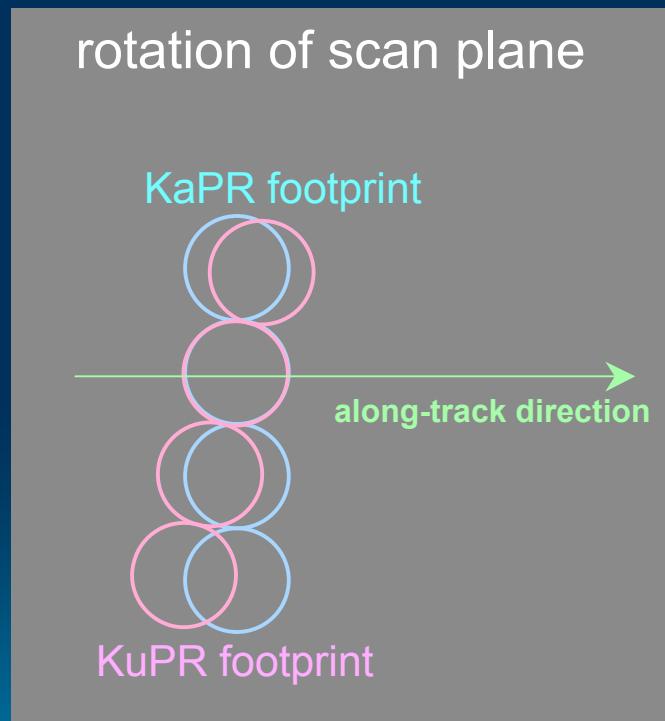
roll (x axis) rotation case



pitch (y axis) rotation case



yaw (z axis) rotation case

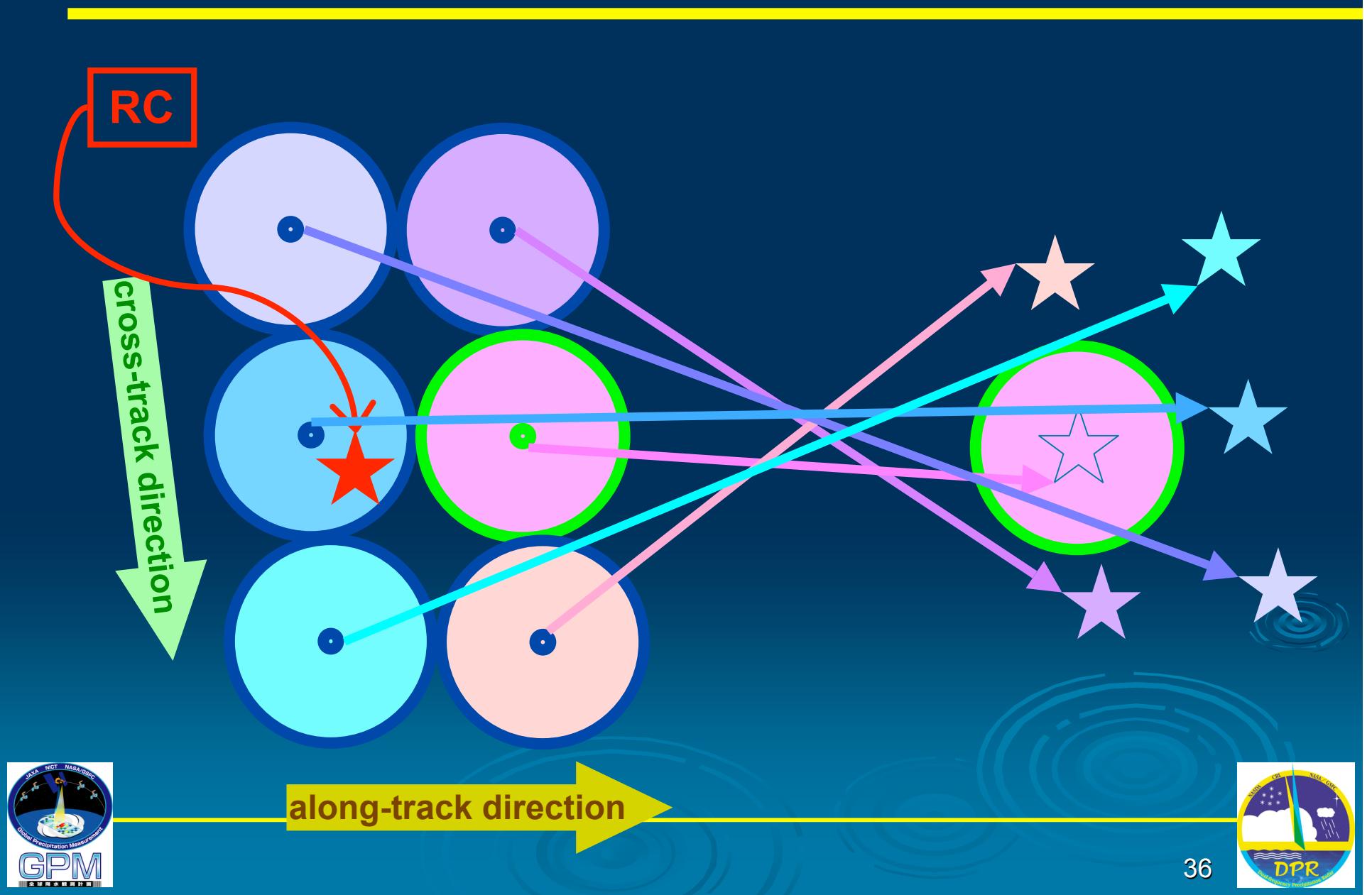


Schedule and procedure of DPR beam adjustment

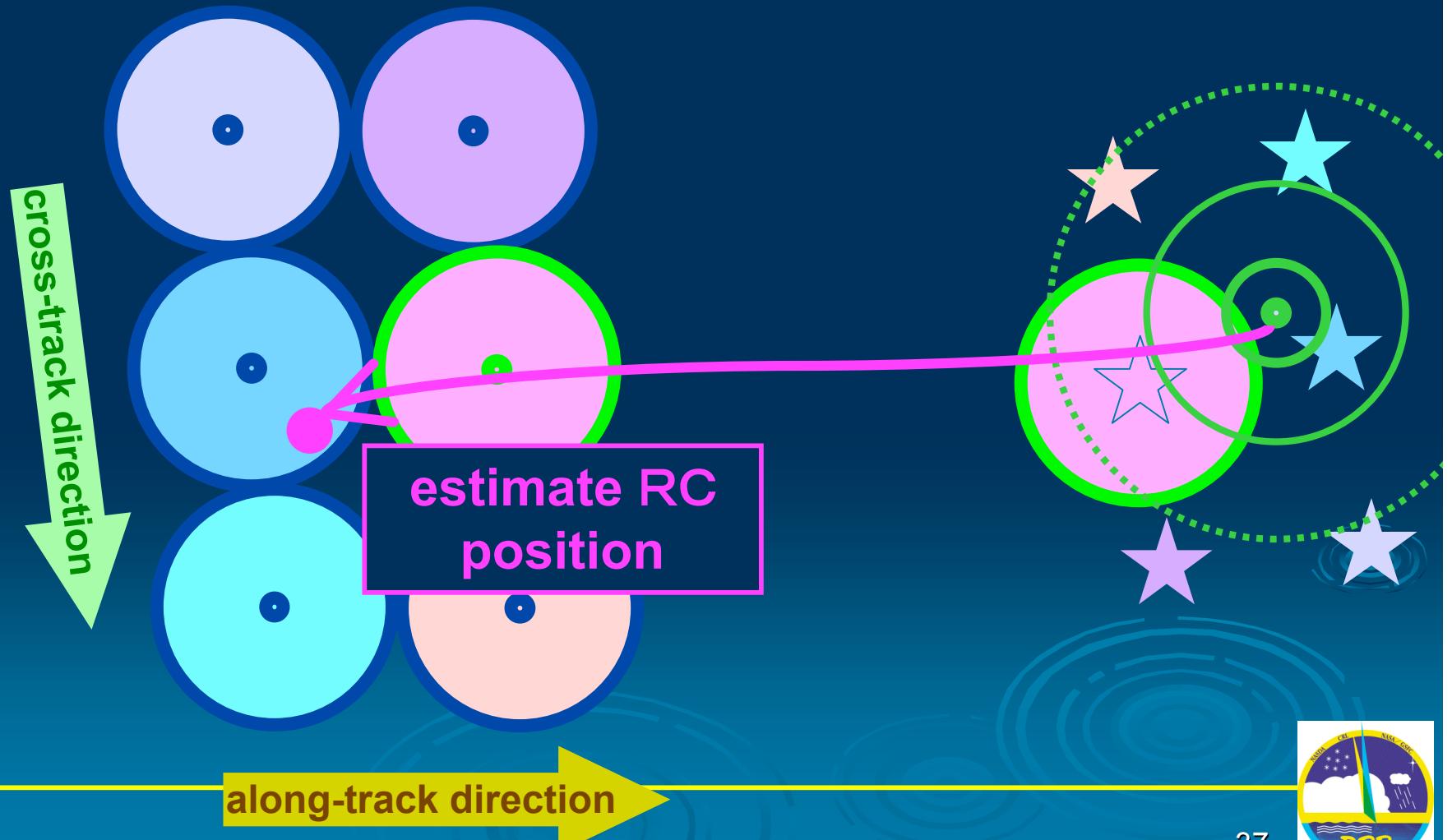
	ground test before launch	initial checkout (two months)	early operational phase (about one year)	operational phase
measurement method of beam direction	<p>far-field measurement at several beam directions the other beam directions estimated from phase and amplitude measurements of TRS</p>	<p>external calibration with radar calibrators</p>	<p>external calibration with radar calibrators (twice per year)</p>	<p>pattern matching with specific echoes</p>
cross-track beam matching		<p>from ground test results</p>	<p>select from good combination of measured at ground test</p>	<p>Phase code data will be changed, if beam-matching is not good.</p>
along-track beam matching			<p>from external calibration results during initial checkout</p>	



Estimation of beam center from external calibration data (1/2)



Estimation of beam center from external calibration data (2/2)



DPR(二周波降水レーダ)の主要性能

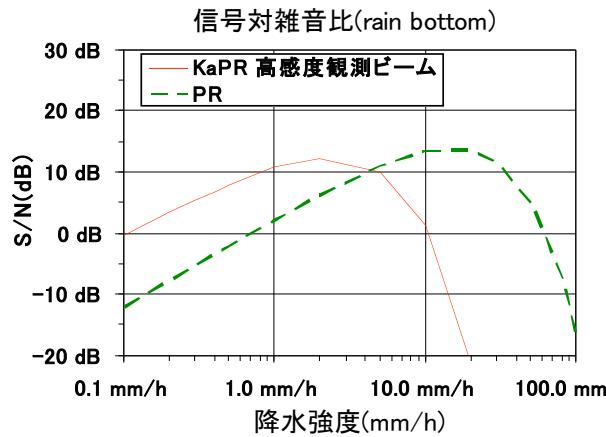
名称	GPM主観観測周波数		TRMM搭載周波数
略称	KaPR	KuPR	PR
方式	アラウンドザリバビリティ		
アンテナ	導波管アンテナ		
周波数	Ka帯35.5 GHz	Ku帯13.6 GHz	Ku帯13.8 GHz
周波数差	2 (35.547 GHz / 35.553 GHz)	2 (13.597 GHz / 13.603 GHz)	2 (13.796 GHz / 13.802 GHz)
尖端電力	> 140 W	> 1000 W	> 500 W
パルス周数	衛星度方向可変(0.0 Hz ~ 4.0 Hz)		固定276 Hz
アーベル幅		0.71 °	
アーチ走査範囲	真方衛星に 斜め上に 45 °	真方衛星に 斜め上に 45 °	
衛星度	平均07 km		平均50 km
観測範囲	125 km	245 km	215 km
水蒸発	5 km		4.3 km
観測モード	高感度モード	二段観測モード	
送信パルス幅	3.2 μsec (x 2)		1.6 μsec (x 2)
レジストリ能	500 m		250 m
観測範囲	高度9 kmまで		高度5 kmまで
最観測範囲 (最観測強度)	< 12 dBZ (0.2 mm/h)	< 18 dBZ (0.5 mm/h)	< 23 dBZ (0.7 mm/h)
測定精度	±1 dB 売		
データ量	KaPRとKuPR 合計1.0 Kbps		< 93.5 Kbps
寸法	1.44 x 1.07 x 0.7 m	2.4 x 2.4 x 0.6 m	2.2 x 2.2 x 0.6 m
質量	< 330 kg	< 450 kg	< 465 kg
使用電力量	< 326 W	< 384 W	< 250 W



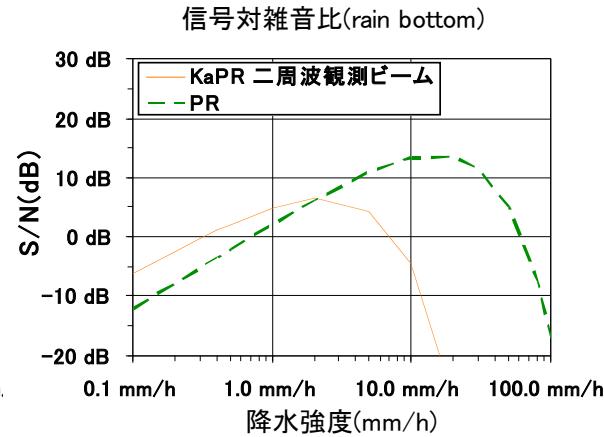
DPRの観測性能

空間的に一様な降雨が高度 5 km まで存在するとした場合の、
地表付近の降雨エコーの信号対雑音比 (S/N) の変化を
横軸を降水強度(対数)にして示す。(点線 TRMM/PR)

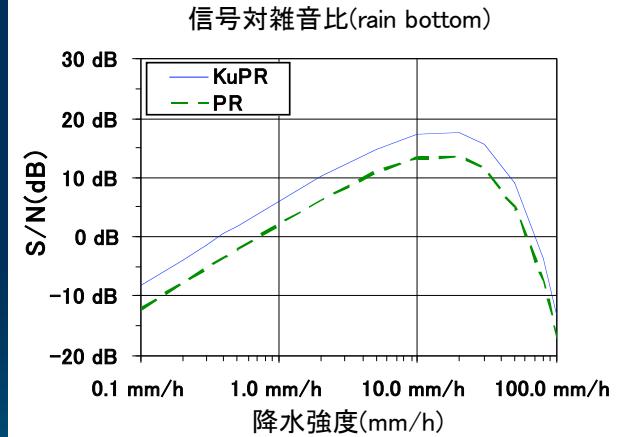
KaPR:高感度観測



KaPR:二周波観測



KuPR



KaPRは周波数が高く、
弱い降雨では PR より感度向上が顕著だが、
強い雨では逆に劣化している。



KuPRは PR より感度向上
(グラフが上にシフト)



System design of ARC

- It is desired that the ARC for Ku- and Ka-band share the antenna.
- Additional receivers can be very simple
 - e.g. Spectrum analyzer + antenna stand.
- Functions
 - The ARC has capability to transmit same frequencies as DPR (incl. dual frequency agility)
 - Transponder with delay loop
 - Synchronizing the clock among ARCs (receivers) using GPS.
- Water vapor measurement is required during ARC operation. (e.g. microwave radiometer)



3-modes of external calibration

Transmit power

ARC: Receiver

Received power

ARC: Beacon

Antenna beam direction

More than 3 ARCs (Receivers)



ARC: Receiver



ARC: Beacon

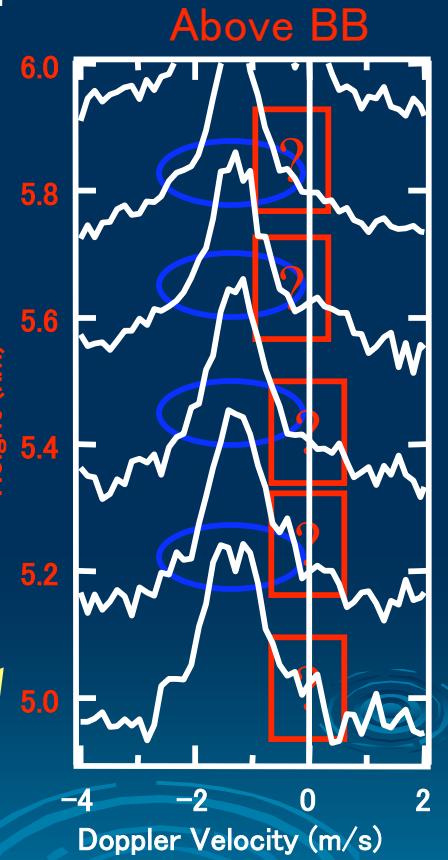
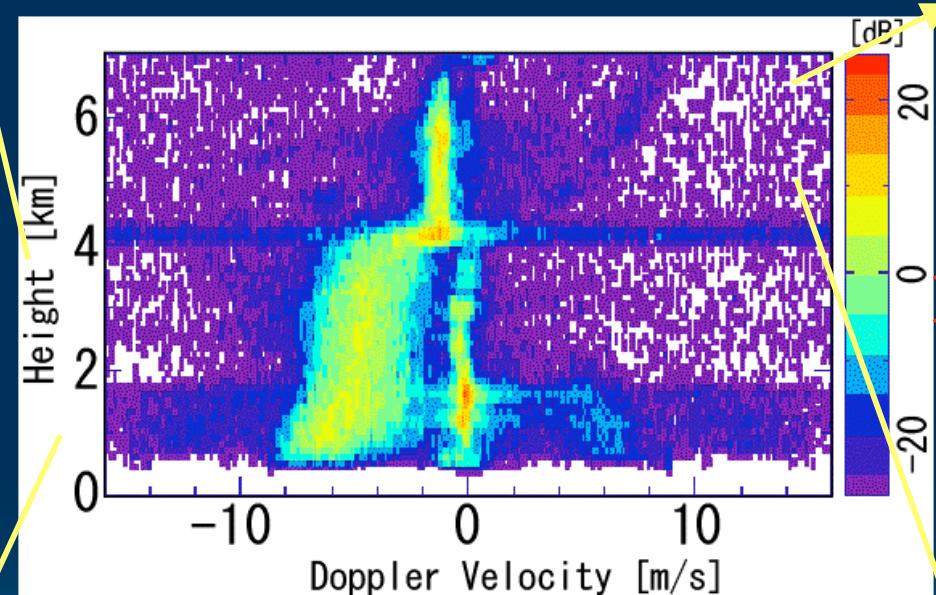
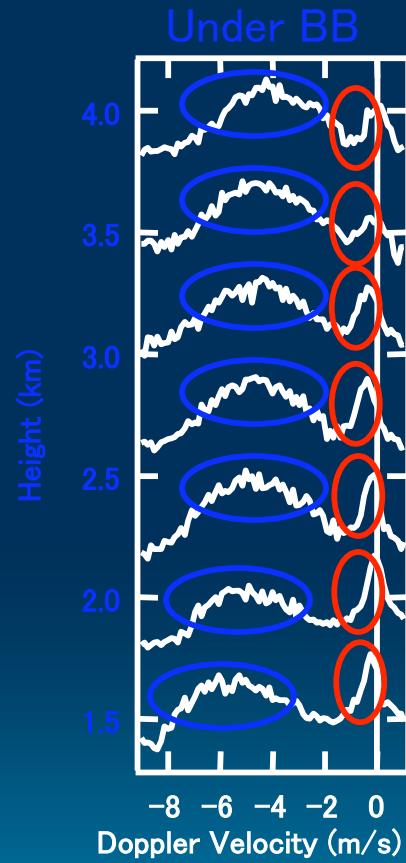


ARC: Transponder



Doppler spectrum observed by the 400MHz WPR

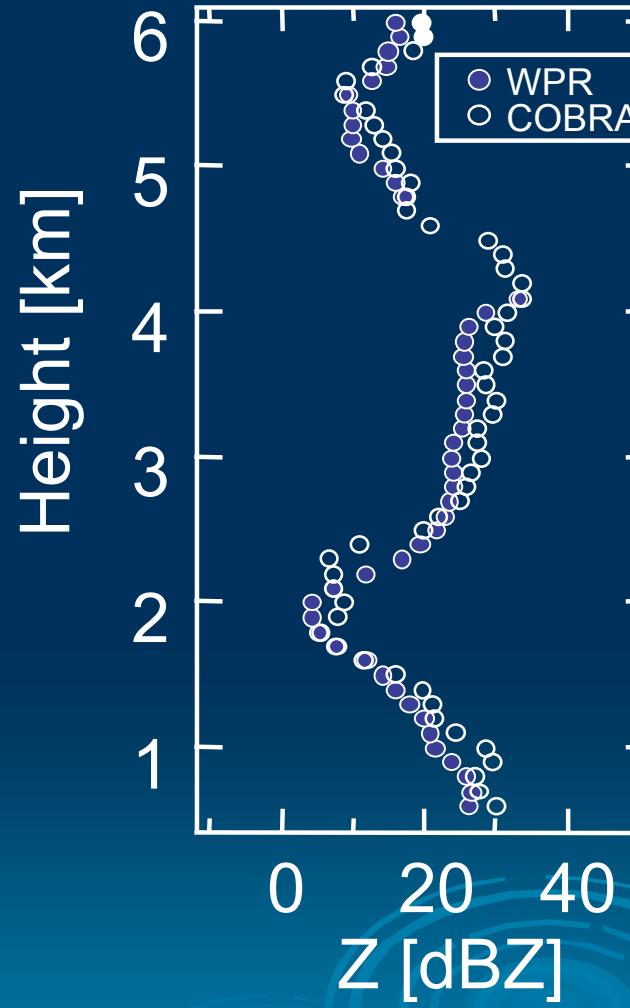
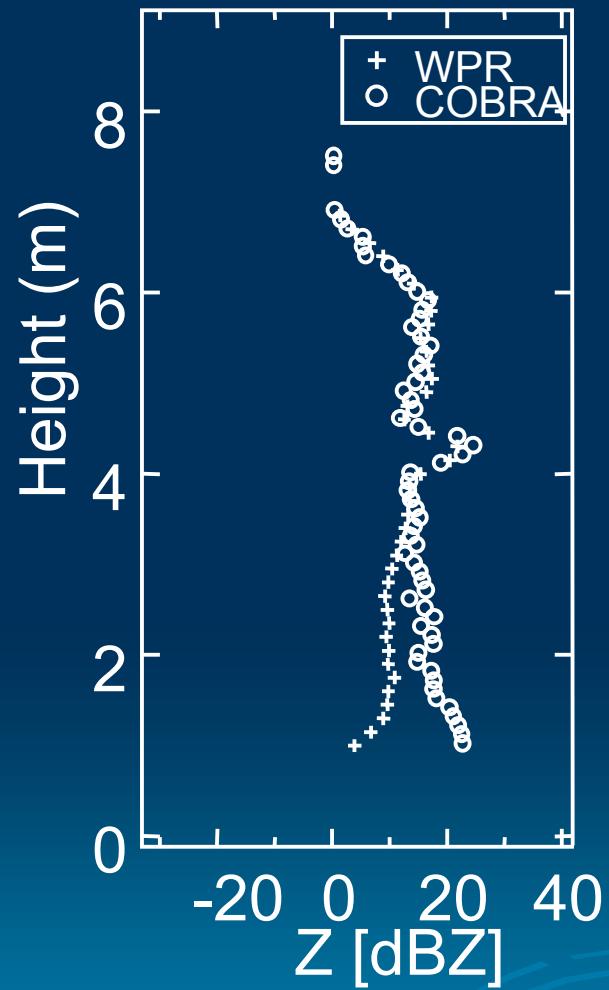
$$S_{obs}(v) = P_t S_t(v) + S_D(v) * S_t(v) + P_n$$

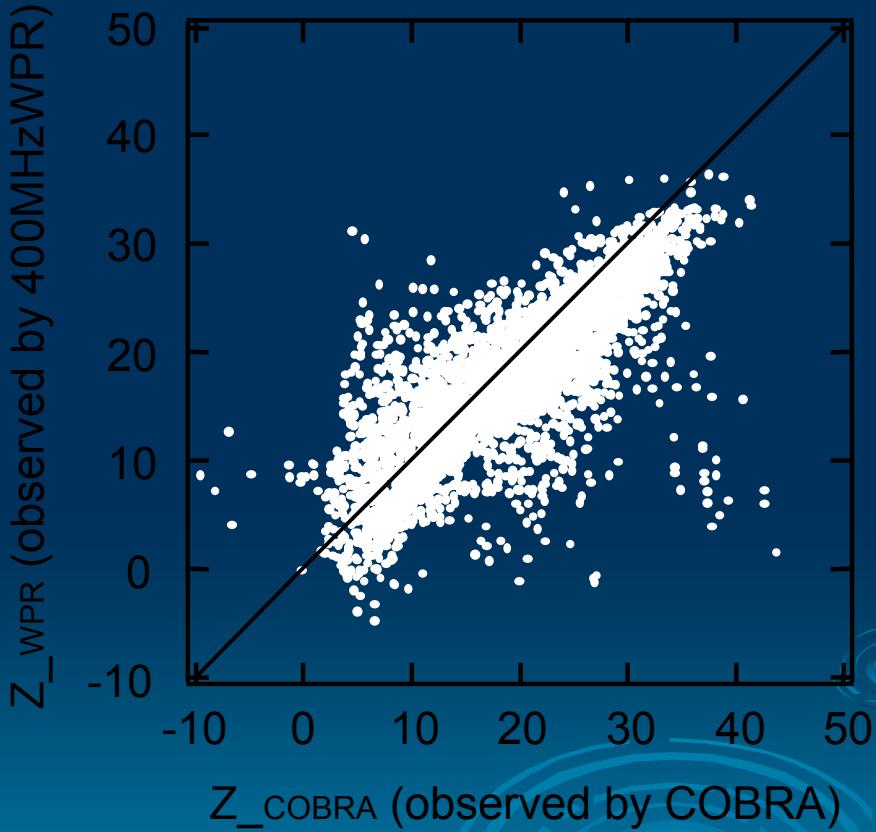
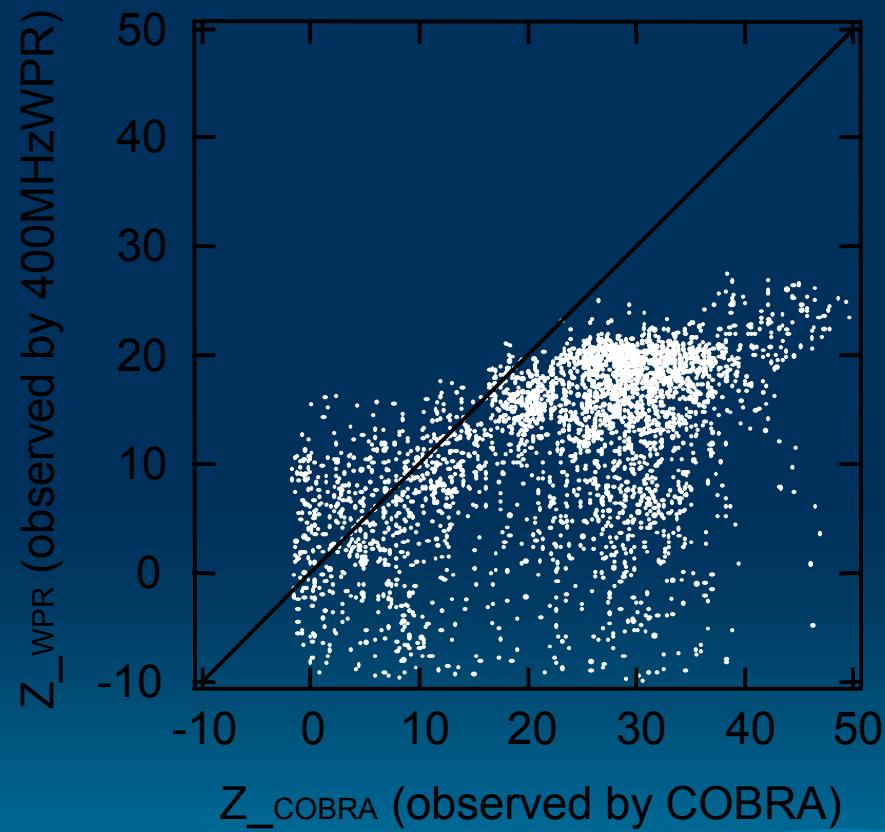


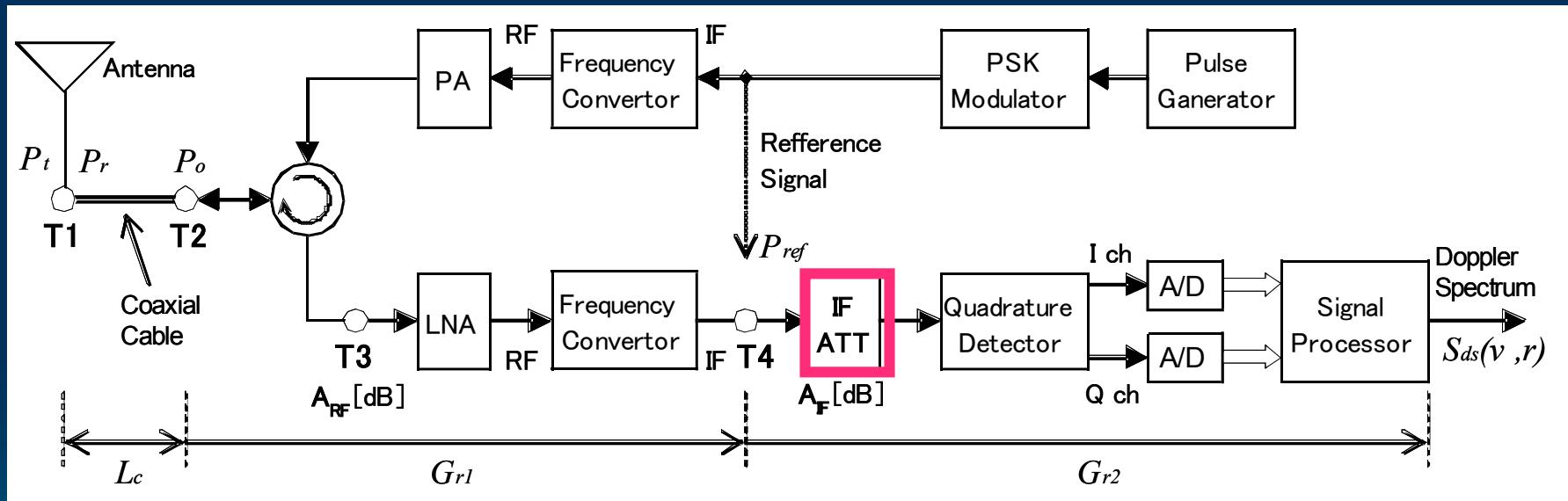
$$S_t(v) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(v - v_0)^2}{2\sigma^2}\right]$$

$$S_D(v) = C \cdot N(D) \cdot D^6 \cdot dD/dv$$











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Rain events

Case1 5/21 06:00~24:00

Case2 5/22 0:00~24:00

Case3-1 5/28 05:00~11:00

Case3-2 16:00~20:00

Case4 5/29 0:00~12:00

Case5-1 6/01 3:00~6:00

Case5-2 6:50~15:00

Case6 6/02 0:00~24:00

Case7 6/03 0:00~4:00

Case8 6/07 20:00~24:00

Case9 6/08 0:00~24:00

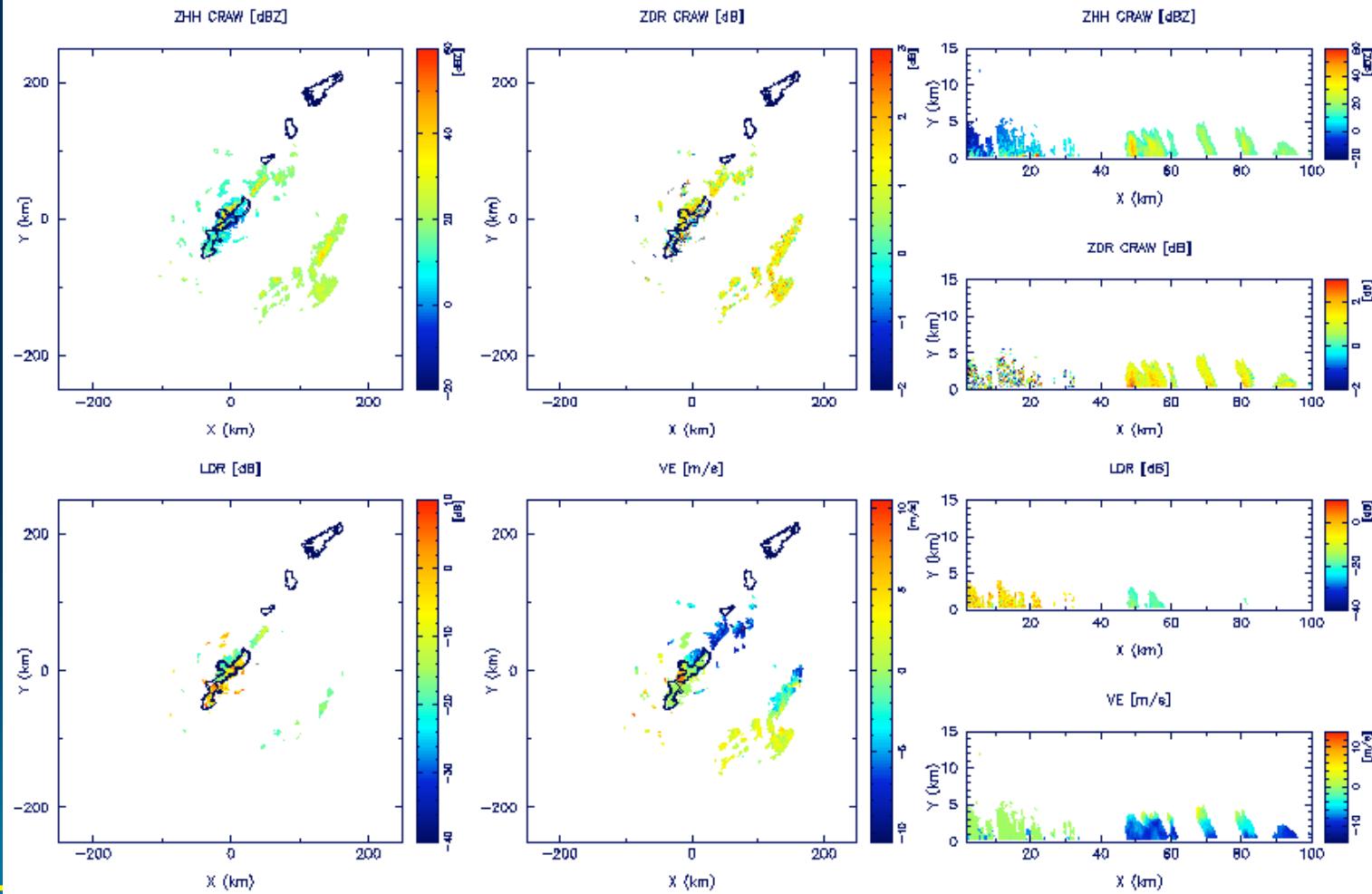
Case10 6/09 0:00~24:00

Case11 6/10 0:00~9:00

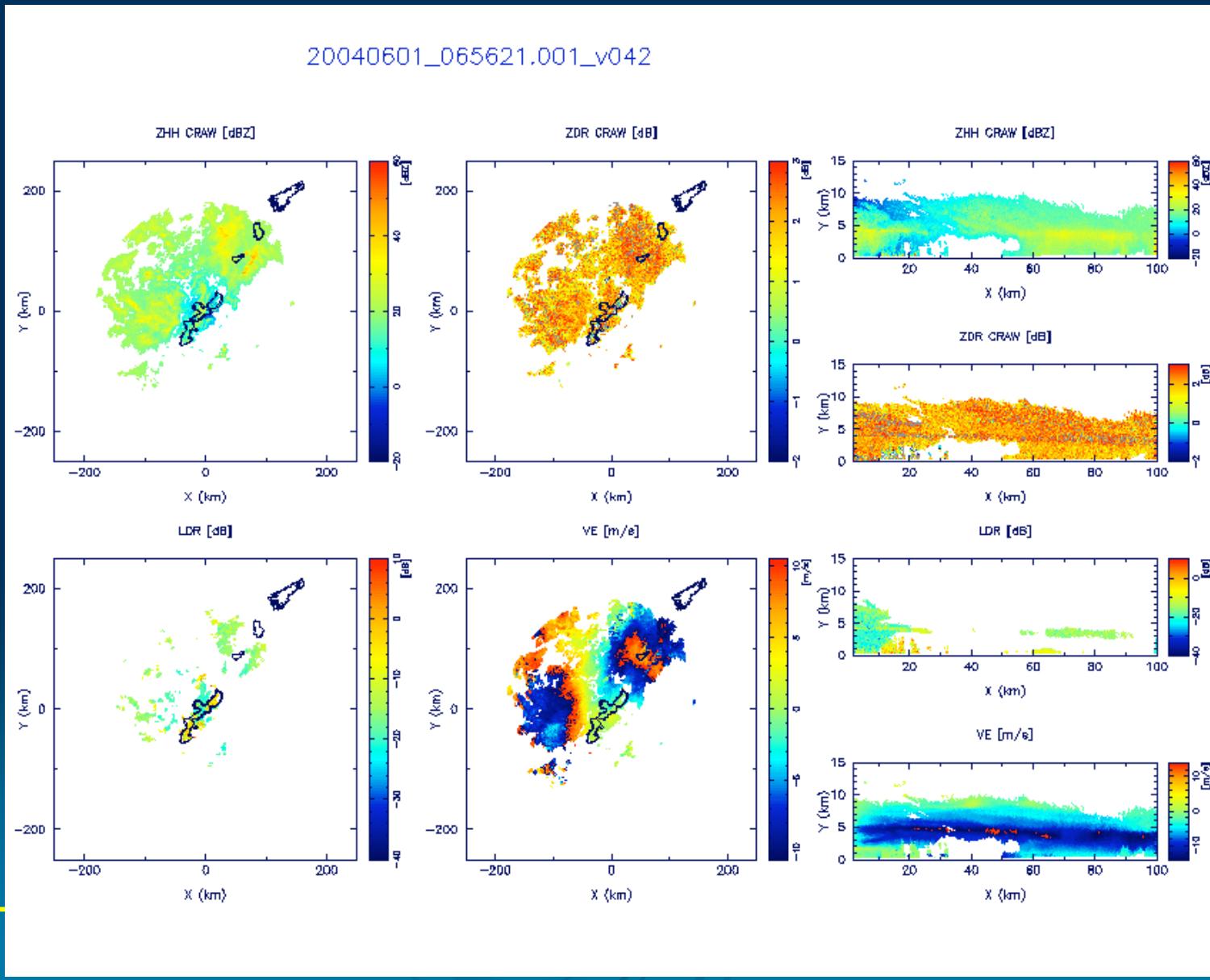


Case3-1 5/28 05:00~11:00

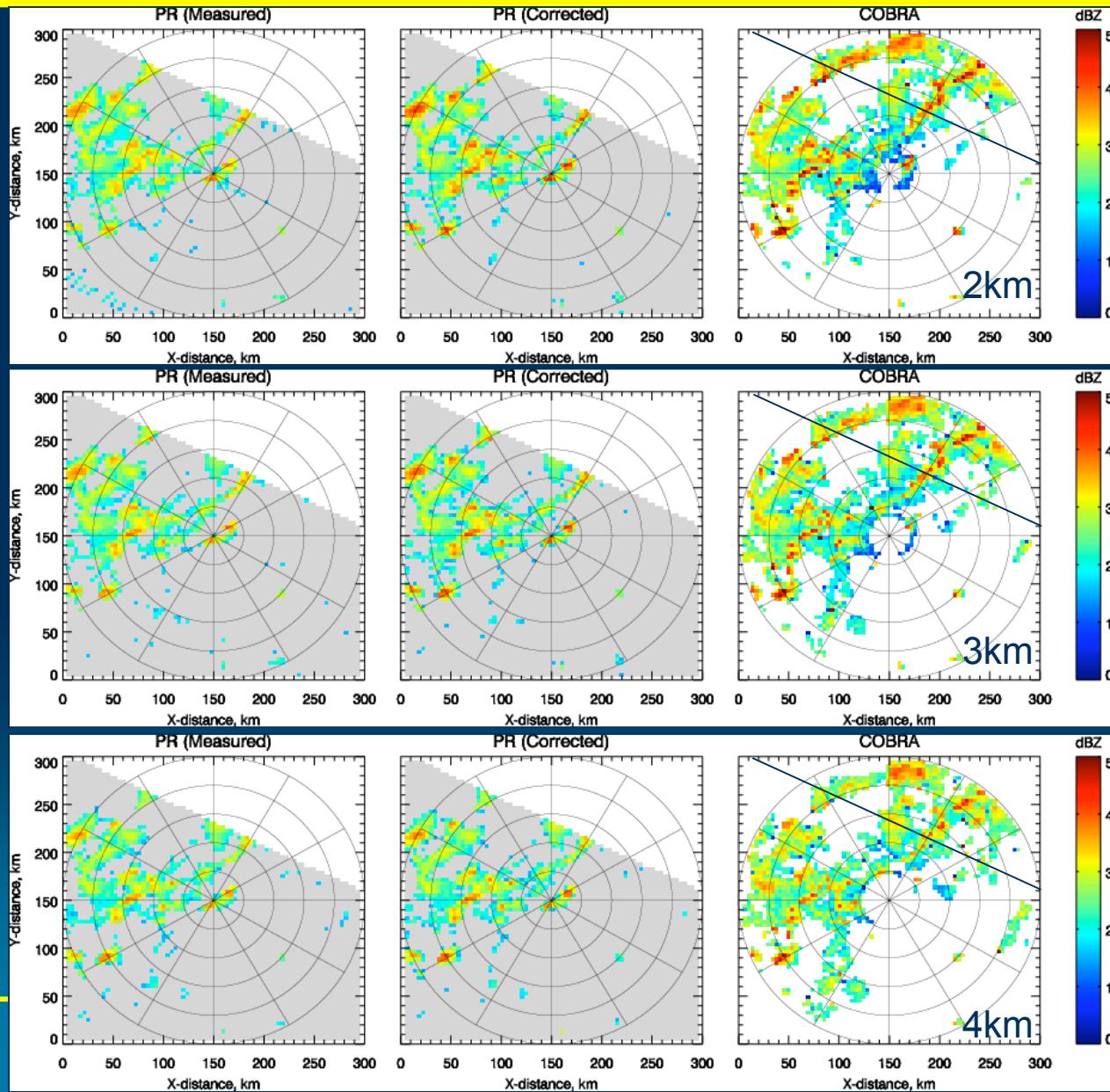
20040528_050621.001_v031



Case6-2 6/1 06:50~15:00



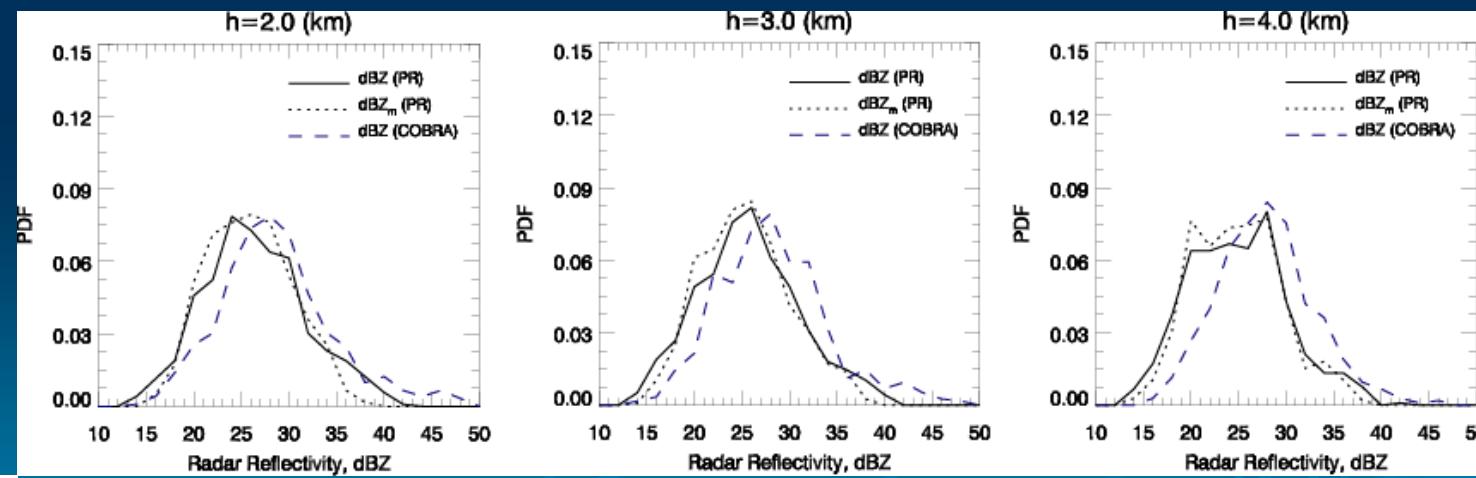
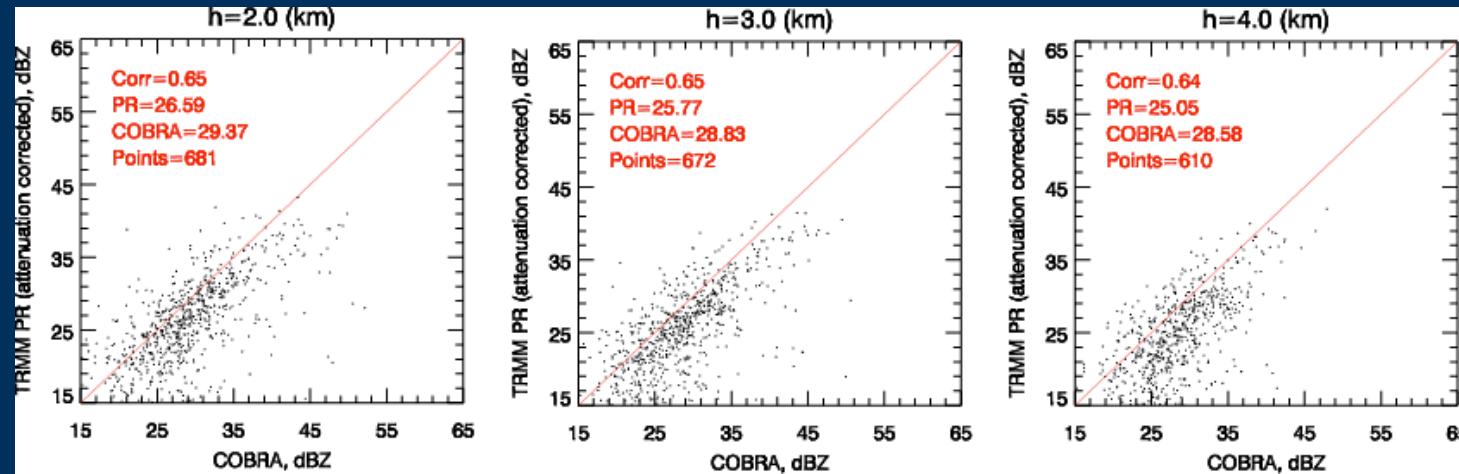
Comparison of horizontal radar reflectivities for the TRMM/PR(2A25) and COBRA



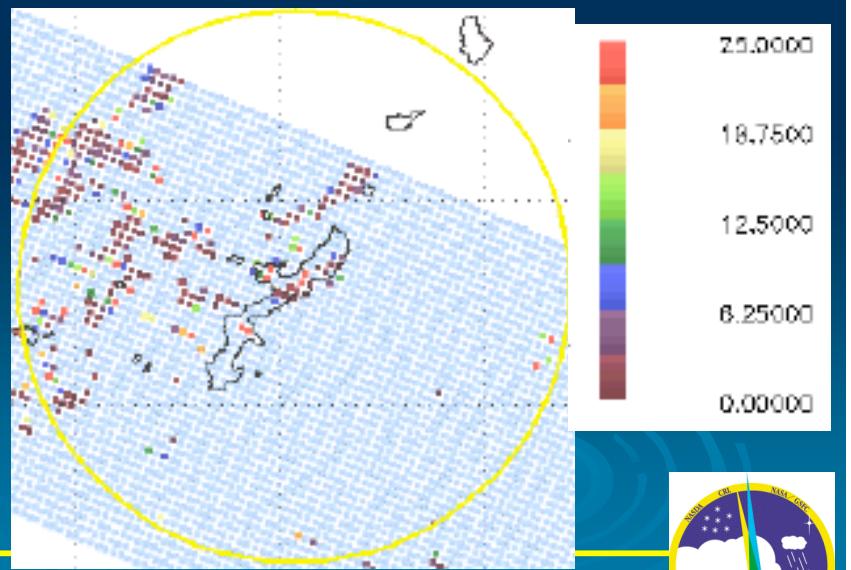
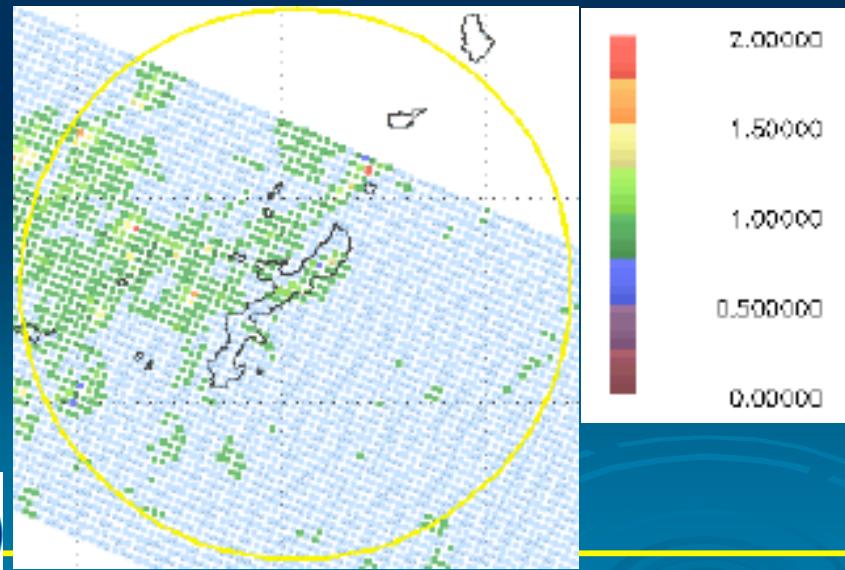
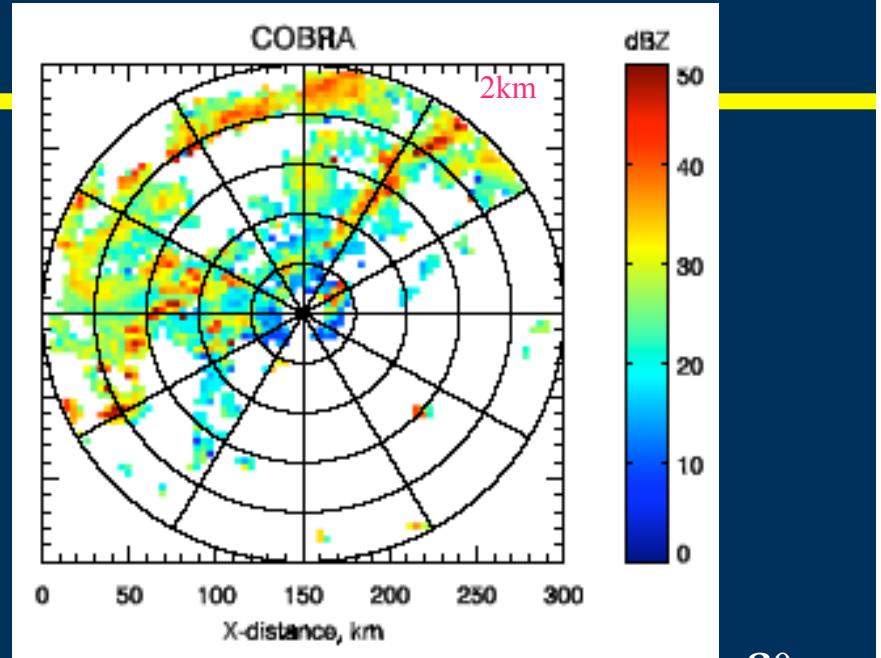
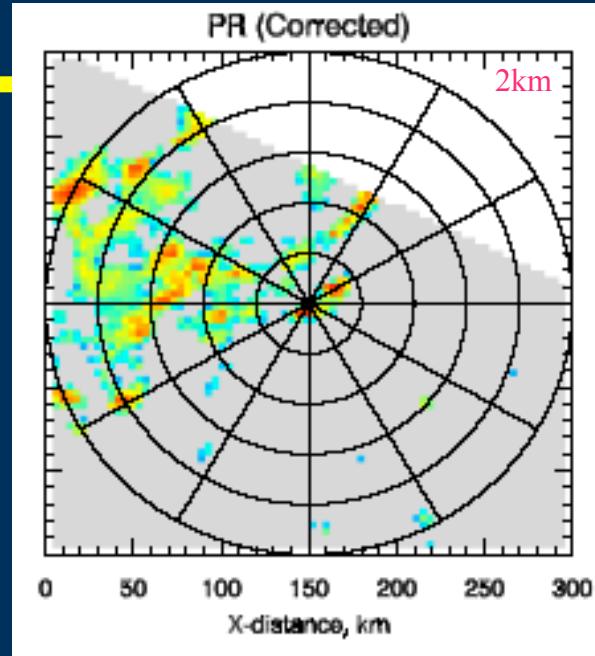
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Scatter plots and The probability density function (pdf)

CASE2



2004/06/02

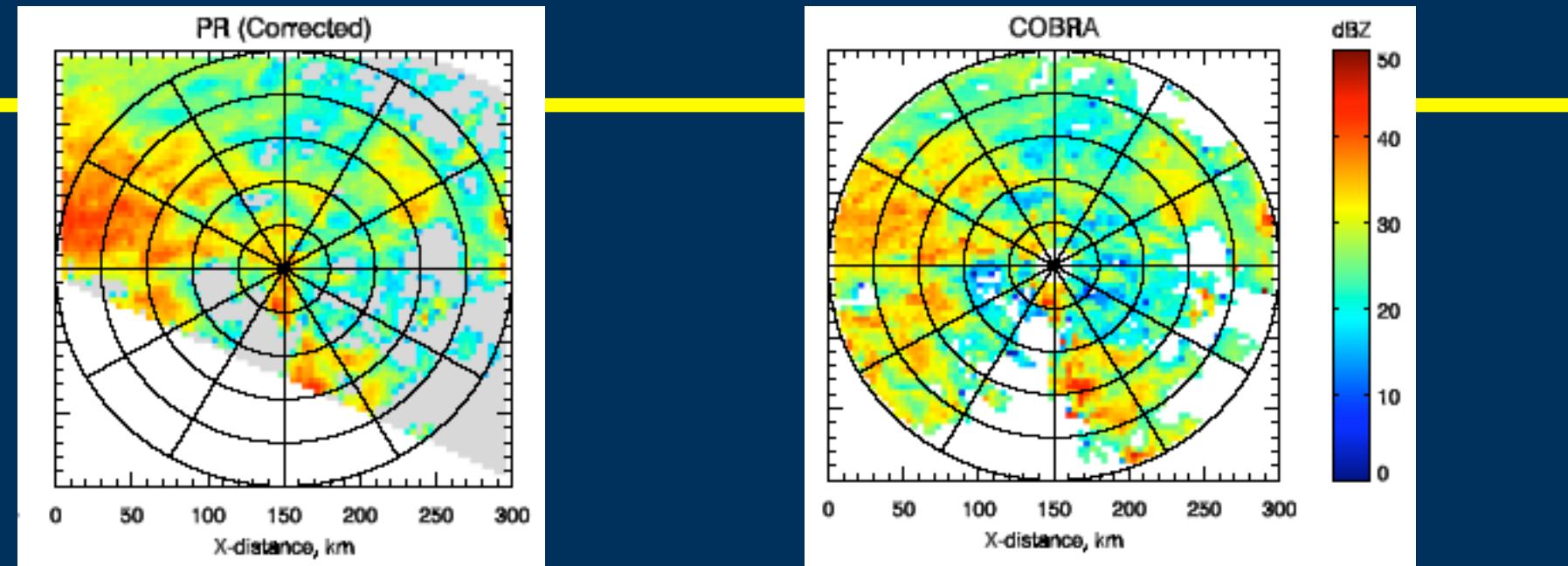


GPM

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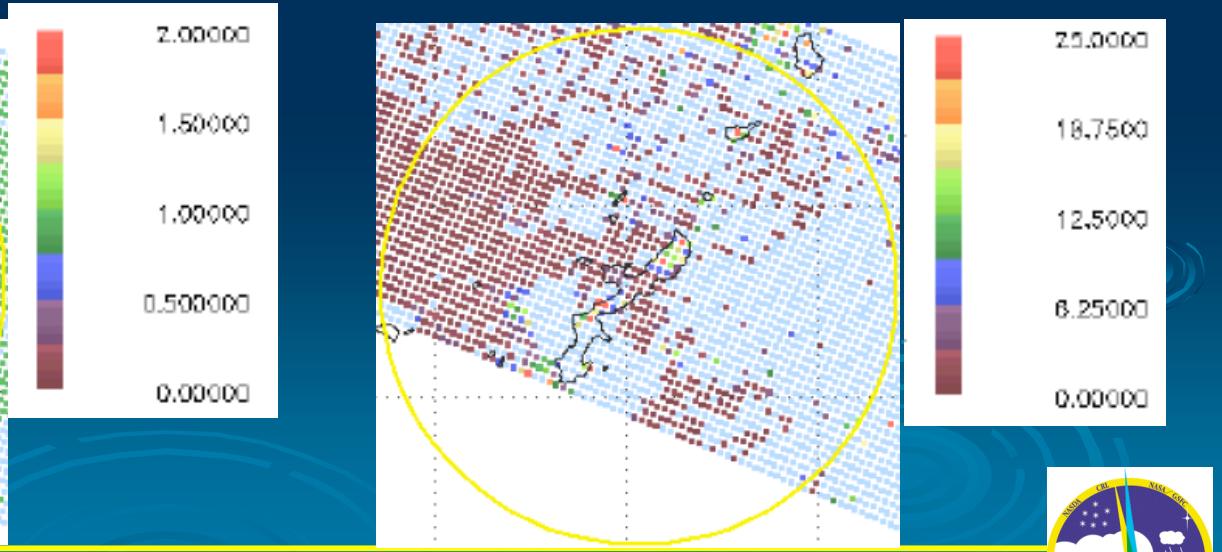
2004/06/09



ε



ε_0



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COBRA/COBRA+

COBRA has been developed from FY2000.

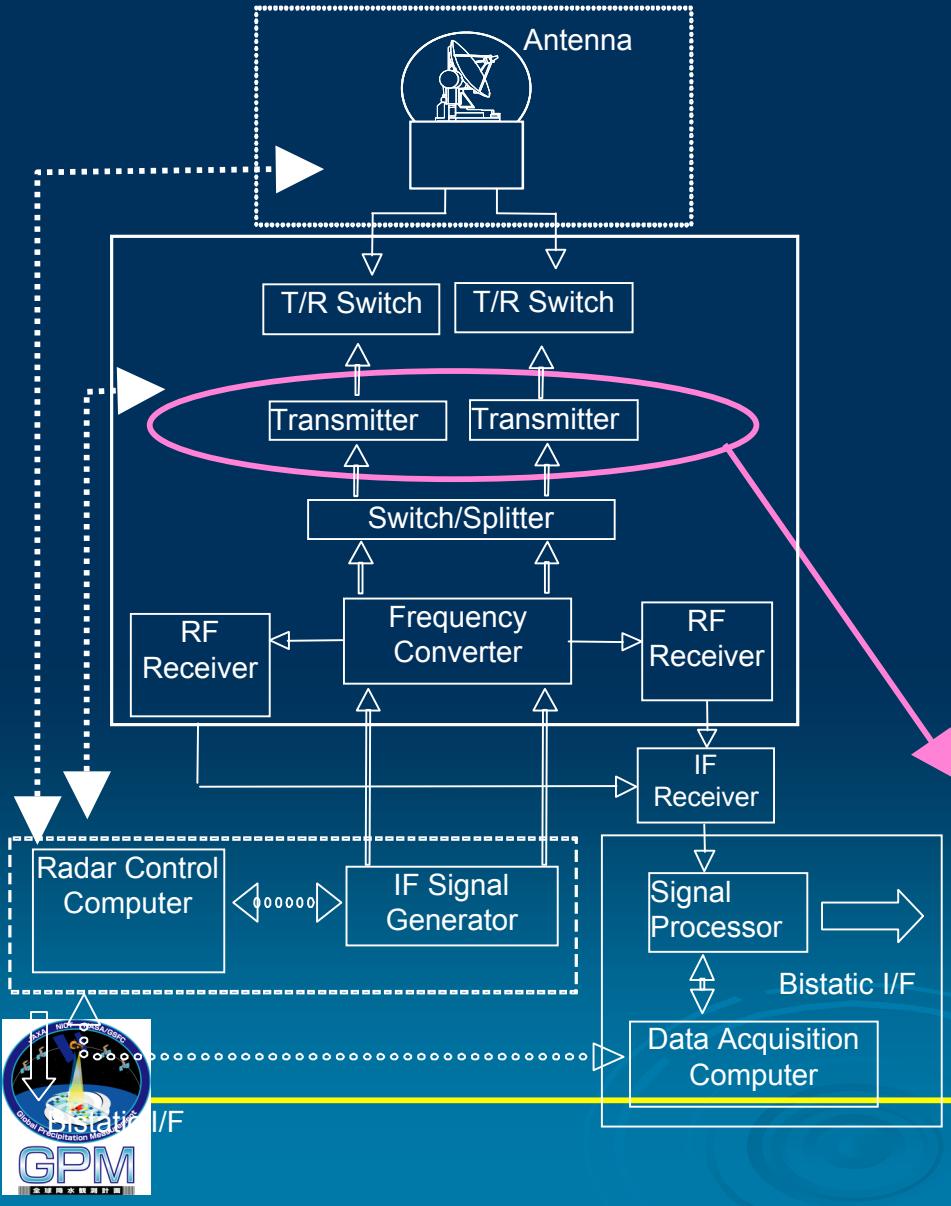
- C-band polarimetric weather radar
- Transmitter type is Klystron
- Polarization observation function
- Bistatic Doppler observation function

COBRA+ has been developed from FY2002.

- C-band pulse compression weather radar.
- Transmitter type is TWT.
- The pulse compression equipment has been added to the COBRA system.
- Polarization observation function



COBRA/COBRA+ Specifications



Peak power	> 250 kW (Dual Klystron) > 10 kW (Dual TWTA)
Pulse width	0.5 μ s, 1.0 μ s, 2.0 μ s (Klystron) 0.5 – 100 μ s (TWTA)
PRF (staggered PRF)	250 Hz - 3000 Hz, PRT 1 μ s step
Antenna size	4.5m φ parabolic
Beam width	0.91deg
Radome size	8m φ
Cross pol. ratio	> 36 dB (Integrated value in a beam)
Antenna gain	45 dBi (including radome)
Sidelobe	< -27 dB (one way)
Ant. scan speed	0.5-10 rpm(PPI), 0.1-3.6 rpm(RHI), 0.1 rpm step
Polarization	H, V, +45, -45, LC, RC (pulse by pulse)

Dual transmitter system

COBRA --- Klystron (x 2)

High power (250 kW)
full polarimetry
Short pulse (0.5, 1.0, 2.0 μ sec)

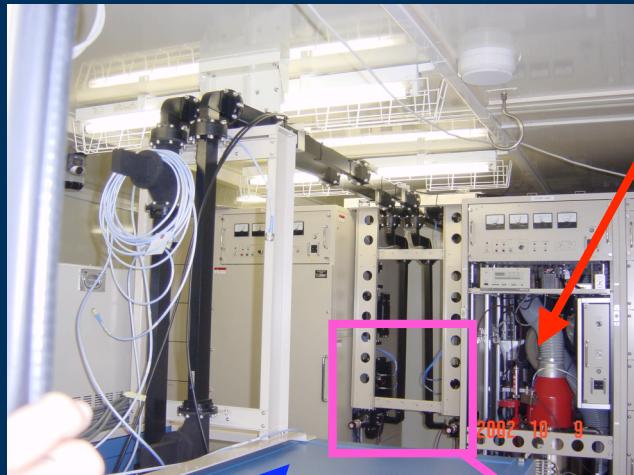
COBRA+ --- TWTA (x 2)

Low power (10 kW)
full polarimetry
Long pulse (0.5 – 100 μ sec)

Transmitter (Klystron/TWT)



COBRA+/COBRA



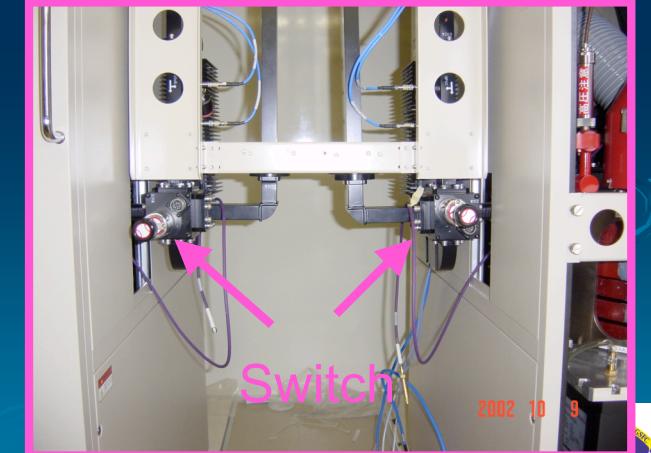
klystron



TWT



Switch



2002 10
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Pictures inside shelter of COBRA/COBRA+

